THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Edited by

GEORGE E. HALE
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SEPTEMBER 1930

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NOTES ON THE [illegible] OF THE BRIGHT-LINE STARS OF CLASS . . . . .

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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

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THE SPECTRUM OF GAMMA GEMINORUM (CLASS A0)

By SEBASTIAN ALBRECHT

ABSTRACT

Results are given of a detailed study of *three spectrograms* of γ Geminorum taken with the *three-prism* stellar spectrograph of the Yerkes Observatory.

Wave-lengths on the international system were determined *for over 900 lines between 4250 and 4723 A*, with an average *probable error of .02 A* and a systematic error probably well within .003 A. Estimated *intensities on a modified Rowland scheme* are included.

Tables I, II, and III, containing the *normal and the Ti reference wave-lengths* and the *radial velocities* derived from the measures, provide the data necessary for a rediscussion of the observed stellar wave-lengths whenever improved laboratory wave-lengths may seem to make a rediscussion desirable.

The *identification* of stellar lines with the elements which give rise to them is *based upon* relatively *accurate observed positions* as well as upon the more *qualitative inferences* drawn from laboratory data and atomic theory.

$H\gamma$ is by far the strongest line, followed by Mg^+ 4481. Two hundred and seventy-six identified lines with intensity >0 are *due in nearly equal proportions to ionized and neutral atoms*. Included in the former are Fe^+, 27 lines; Ti^+, 36; Cr^+, 11; Sc^+, 7; Ce^+, 15; Zr^+, 7; Sa^+, 5; Rb^+, 5; V^+, 4; Mo^+, 4; Mn^+, 4; Mg^+, 3; Pr^+, 3. Among the latter are *Fe*, 42; *Ti*, 17; *Cr*, 17; *Mn*, 9; *Ca*, 7; *V*, 5; and *Ni*, 4. Other elements which have measured lines are Al^+, *Ba* and Ba^+, La^+, *Bi* and Bi^+, Ni^+, *Ru*, *Pb*, *Nd*, Y^+, Cs^+, Eu^+, *Sb*, and *Er*. *Pt*, *As*, *Os*, *Ho*, and *Yb* seem to be absent, while Gd^+, Zn^+, *Te*, *Sr*, *Nb*, *Ir*, *Co*, Ag^+, *S*, and *Cl* are indeterminate. About *80 "distinctive" lines* are present.

There seem to be no appreciable *relative displacements between lines* due to *neutral* and those due to *ionized* atoms.

This and similar studies of typical stars of each spectral class will remove most of the *uncertainties* attached to the assignment *of normal wave-lengths* to measured lines for the determination of general and individual displacements. Many important problems in which the fundamental nature of the results become significant, particularly the K-term and associated results, such as the rotation of the galaxy as derived therefrom, are inextricably involved.

The assignment of normal wave-lengths to measured lines for the determination of general displacements of stellar spectra in the routine of radial velocity and wave-length determinations is usually

attended with more or less uncertainty, owing to our incomplete knowledge of the components which may be involved to form the blends. This is true for all spectral classes from A to M. The apparent simplicity of the spectrum of class A is somewhat illusory. Although the enhanced spectra of three or four elements are quite prominent in class A they do not dominate the spectrum as completely as at first they appeared to do. Many of the stronger lines proved to be double, the components being due to neutral or ionized atoms or to both. Moreover, a somewhat detailed study revealed hundreds of fainter lines in even the short region of spectrum usually photographed with three prisms which a cursory examination had not disclosed. Thus, the simplicity of all measured lines becomes somewhat uncertain and cannot be assumed a priori.

It is true that when many lines are employed for the determination of general displacements some of the effects of duplicity of lines are minimized, owing to the fact that they then assume more or less the character of accidental errors. The situation is nevertheless unsatisfactory even when only general displacements are concerned, because under such conditions the underlying basis is not established. The effects of duplicity assume an unusual importance in problems in which the fundamental nature of the results become significant.

A detailed study with the dispersion of at least three prisms of a typical star of each spectral class would constitute a very material aid in an intelligent assignment of normal wave-lengths for radial-velocity determinations and related problems, and for various studies concerning conditions in stellar atmospheres. For example, the reality of the K-term, which has received several different interpretations and which was employed recently in a very interesting paper as evidence for a rotation of the galaxy, being a by-product of radial-velocity determinations, is intimately tied up, among other things, with the sets of normal wave-lengths employed in the reductions for radial velocity. Next to class G, for which important independent checks are available and for which the K-term is practically zero, class A is perhaps the most readily amenable to treatment, owing to the relatively greater simplicity of its spectrum.

Below are given the results of a study of the spectrum of γ

Geminorum, of class Ao. Spectrograms taken at the Yerkes Observatory with three prisms were kindly placed at the disposal of the writer by Director Frost. They were measured with a new Gaertner spectro-comparator, with use of a daylight lamp as a source of constant light for the illumination of the spectrograms.

Tables I and II give the wave-lengths for the stellar and the reference lines, respectively, which were employed in the reductions

TABLE I

STELLAR LINES EMPLOYED IN THE REDUCTIONS OF MEASURES

Normal λ	No. of Plates	Normal λ	No. of Plates	Normal λ	No. of Plates	Normal λ	No. of Plates
4287.406....	1	4351.768....	3	4449.143....	1	4548.094....	1
4290.222*...	2	4352.740....	2	4450.487*...	3	4549.593....	1
4294.123*...	3	4367.657*...	3	4451.58.....	2	4553.96.....	2
4294.78.....	1	4374.495....	1	4453.707....	1	4555.904*...	3
4295.755....	1	4383.550*...	3	4456.334....	1	4558.654*...	1
4296.56*....	2	4385.39*....	3	4459.64.....	1	4563.757*...	3
4299.141....	2	4386.858*...	3	4464.458....	2	4571.970*...	3
4300.052*...	3	4390.977....	2	4465.807....	1	4576.31*....	3
4301.928....	1	4391.755....	1	4468.493*...	3	4583.838*...	3
4303.18*....	2	4395.036*...	3	4469.385....	1	4588.206*...	2
4307.862....	3	4395.848*...	2	4470.129....	1	4589.961*...	3
4312.866*...	3	4399.770*...	3	4476.024....	3	4592.056*...	2
4314.12.....	1	4414.54.....	1	4481.229*...	3	4616.627....	1
4314.979*...	2	4415.124*...	3	4488.319*...	3	4618.763*...	2
4316.807....	2	4416.81.....	1	4489.21.....	3	4629.327*...	3
4320.75.....	1	4417.718*...	3	4491.399*...	3	4632.15.....	1
4320.97.....	1	4418.340....	3	4501.269*...	3	4634.076....	1
4322.52.....	1	4421.949*...	3	4508.287*...	3	4666.207....	1
4325.00.....	1	4426.055....	1	4515.337*...	3		
4337.915....	1	4443.799*...	3	4522.630*...	3		
4340.466*...	3	4444.267....	2	4533.966....	3		

* See footnote to Table III.

and which therefore form the basis for the observed stellar wave-lengths. The indicated number of plates for which each normal and reference line was used may, without danger of the introduction of appreciable errors, serve as a weight in discussions contemplating readjustments of the system. The list of normal wave-lengths could readily be somewhat improved for future use by omitting some lines (such as 4295.7 and 4299.1) and by changing the wave-lengths for lines for which this study indicates improved identifications. In reductions for which practically the entire list of lines is employed, no appreciable gain would result from such a revision, but when only a

small number of lines is to be used the result might be quite materially affected. For the few strong apparently double lines it is usually possible to find probable identifications for the components,

TABLE II

WAVE-LENGTHS EMPLOYED FOR TITANIUM REFERENCE SPECTRUM

λ Employed	Observed			λ Employed	Observed		
	λ	No. of Plates	Intensity		λ	No. of Plates	Intensity
4263.134	.....	.....	1	4455.319	.316	3	2
4274.585	.....	.....	1	4457.427	.429	3	3
4286.006	.011	2	2	4464.458	.467	2	1
4289.072	.080	2	2	4465.807	.811	1	1
4290.222	.231	3	6	4468.493	.486	3	15
4294.103	.088	3	6	4481.259	.249	3	2
4295.751	.747	3	1	4488.319	.311	3	3
4298.666	.671	3	2	4489.089	.069	2	1
4300.052	.042	3	8	4496.146	.151	3	0
4301.089	.067	1	4	4501.269	.273	3	12
4301.928	.925	3	2	4512.734	.728	3	2
4305.910	.908	3	8	4518.024	.023	3	4
4307.862	.873	3	4	4522.797	.799	3	4
4312.866	.877	3	5	4527.305	.307	3	3
4320.965	.967	2	0	4533.966	.968	3	7
4337.915	.916	3	8	4534.782	.791	1	6
4341.369	.372	2	0	4544.689	.699	3	1
4344.291	.282	2	1	4549.624	.636	3	14
4367.657	.666	3	2	4552.454	.441	3	3
4374.825	.822	2	0	4555.485	.488	3	3
4386.858	.860	3	1	4563.757	.735	3	10
4394.057	.045	1	00	4571.970	.973	3	14
4395.036	.013	3	12	4589.961	.953	3	1
4399.770	.771	3	4	4617.270	.270	3	4
4404.316	.310	2	1	4623.098	.101	3	2
4411.080	.060	3	2	4629.337	.339	2	1
4417.718*	.740	3	4	4645.194	.173	1	0
4427.098	.104	3	4	4656.468	.465	3	2
4443.799	.781	3	12	4667.585	.587	3	3
4449.143	.146	3	3	4681.909	.908	3	4
4450.487	.478	1	4	4691.334	.340	2	1
4450.893	.928	1	2	4698.763	.776	2	1
4453.308	.330	1	2	4710.187	.154	1	0
4453.707	.695	1	1				

* Close Companion toward violet.

which in most cases are of unequal intensity. However, the possibility of a reversal is not excluded, where, as for 4303.18, the best accordance is found in the observed mean position.

In the derivation of stellar wave-lengths it becomes necessary to remove from the measured positions of lines the systematic displace-

ments of the spectrum, all of which may, as is customary, be included in the radial velocity. Table III gives the radial velocities and other data concerning the three spectrograms which were employed. The first line gives the displacements which were actually employed. The revisions indicated in lines 2 and 3 would produce systematic changes in the observed wave-lengths of +.001 and +.002 A, respectively.

Wave-lengths on the international system are given in Table IV for over 900 stellar lines between λ 4250 and λ 4723, with an average probable error of approximately 0.02 A and with a systematic error

TABLE III

Plate	B 236	B 249	A 486
Emulsion	Cramer Crown	Cramer Crown	Seed 27
Date (G.M.T.)	1901 Nov. 15.748	1901 Nov. 27.767	1904 Dec. 6.940
	km/sec.	km/sec.	km/sec.
Displacement used	−35.38	−31.39	−18.6
Displacement obtained from 43 selected lines	−35.36	−31.66	−18.54
Displacement from 39 of the 43 selected lines*	−35.36	−31.60	−18.80
Reduction to sun:			
Va	+20.70	+15.81	+11.45
Vd	+ 0.23	+ 0.14	− 0.25
Radial velocity	−14.43	−15.65	− 7.60

* Omitting 4 lines which were measured on less than three plates. The 39 selected lines are identified in Table I by asterisks. In deriving the radial velocities from 43 and 39 selected lines the normal wave-length of 4618.763 was changed to .79.

probably well within 0.003 A. Owing to the large number of lines (81) used in the reductions, the presence among them of a moderate number of the blends with appreciable separation of components does not materially affect the system, as is demonstrated by the random distribution of residuals for 64 additional lines which had not been employed in fixing the system. The mean, weighted according to the number of observations, of the 64 differences "stellar minus laboratory wave-lengths" is less than .001 A.

The recorded intensities in Table IV, which are the means of visual estimates made at the times of measurement, follow roughly the Rowland scheme except that, in conformity with recent practice,

TABLE IV

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4250.27.....	1	2	h	.13 *Fe*
4250.72.....	1	1	h, mod n	.79 *Fe* dist; .68 Mo^+
4251.05.....	1	1	h	.....
4251.45.....	1	1	n, h	.48 *Pr*
4251.71.....	1	1	n, h	.7 Mn^+; .75 Gd^+; *Ti*
4252.00.....	1	0	n, h	.92 *Er*
4252.35.....	1	0	b, H	.45 Nd^+; .30 *Co*
4252.63.....	1	4	b, H	.6 Cr^+
4254.5.....	1	10	v.b, H, several lines	.34 *Cr*, dist; *Fe*; .42 *Ho*; .43 Pr^+; .73 Ce^+
4255.7.....	1	3	H	.79 Ce^+; .85 *Fe*
4256.45.....	1	0	absorp near	.33 Dy^+; .40 Sa^+
4256.72.....	1	1	H	.69 *Ca*
4257.72.....	1	1	H	.66 *Mn*
4258.15.....	1	3	b, H	.16 Fe^+; .04 Zr^+
4258.49.....	1	— 1	H	*Fe*?
4258.87.....	1	1	n	.95 *Fe*
4259.23.....	1	1	b, d? H	.15 *Cr*; .26 Mn^+
4259.70.....	1	2	b, h	.64 Bi^+
4260.54.....	1	4	b, H	.48 *Fe*; dist
4261.98.....	1	3	b, h	.90 Cr^+; .09 Gd^+
4262.68.....	1	— 1	H, p	.68 Sa^+
4262.95.....	1	1	h	.....
4264.69.....	1	— 1	H, p	.72 *Fe*; .68 $Cs^{(+?)}$
4265.08.....	1	0	b, def, p	.88 V^+; .89 Zr^+; .07 *Sa*; .08 *Sb*
4266.05.....	1	1	half, p	.92 *Mn*; .23 *Ti*
4266.59.....	1	— 2	H, p	.62 $Rb^{+?}$; .70 Zr^+
4267.24.....	1	2	H	.1 C^+, *d*
4267.54.....	1	1	H	.....
4267.77.....	1	1	H	.83 *Fe*
4268.01.....	1	2	H	.09 *Ir*
4268.27.....	1	2		.....
4268.55.....	1	1	h merged	.64 *V*
4268.78.....	1	0	h merged	.75 *Fe*; *Gd*
4269.00.....	1	1	h merged	.12 *Pr*
4269.19.....	1	0	h merged	.30 Cr^+
4269.39.....	1	1	h merged	.39 *W* dist
4269.57.....	1	0	h	.51 La^+ dist
4269.96.....	1	1	h	*Cr*
4270.27.....	1	1		.14 *Ti*; .19 Ce^+
4270.57.....	1	1	v.n	.7 Ce^+ dist
4171.16.....	1	4	v.b, H, several lines?	.16 *Fe* and ?
4171.82.....	1	6	v.b, H	.77 *Fe* dist; .87 *Ca*; .64 and .96 *Fe* Pred ?
4272.70.....	1	1	b, H, p	.84 Hf^+; .9 *Cr*
4273.18.....	1	3	H	.18 $Rb^{+?}$ dist
4273.37.....	1	.....	d, H	.31 Fe^+; .31 *Ti*
4273.56.....	1	3	H	.49 Zr^+
4274.35.....	1	0	H	.4 Mo^+; .41 *Ti*
4274.62.....	1	1	H, p	.59 *Ti*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4274.74.....	1	0	H, p	.80 *Cr* dist
4274.97.....	1	1	H, v.p	.09 *Nd;* .11 *Cu ?*
4275.70.....	1	0	h, p	.56 Cr^+; .65 La^+
4277.12.....	1	— 1	v.n, real?	.1 Cs^+?
4278.26.....	1	2	p	.13 Fe^+; .23 *Fe, Ti;* .28 *Ca*
4278.48.....	1	— 2	H	.54 *Tb*
4278.76.....	1	0	n, def	.68 *Mn;* .7 *As;* .80 *Ti*
4279.02.....	1	— 1	n, H	.00 Cr^+ Pred; .04 Mo^+
4280.36.....	1	1	b, H	.34 Cr^+ Pred; .20 *Zr;* .27 *La;* 54 *Gd*
4280.79.....	1	— 1	H, v. indist, p	.79 Sa^+
4181.1.....	1	.....	absorp, not m	.08 Cr^+ Pred; .10 *Mn*
4282.12.....	1	0	h } merged	.06 Th^+; .20 Zr^+
4282.33.....	1	— 1	h, half } merged	.48 Mn^+
4283.05.....	1	0	H, poor; B 249	.01 *Ca* dist
4283.16.....	1	1	B 249	.12 *Ba* dist
4283.36.....	1	1	f	.....
4283.69.....	2	0	p	.80 Mn^+
4284.17.....	1	1	h	.20 Cr^+; .09 *Mn;*. 06 V
4284.52.....	1	— 2	H, p	.40 *Ca;* .50 Nd^+
4284.94.....	1	— 2	n, absorp to vi	.98 *Ti;* .97 *S*
4285.25.....	1	2	half; real?	.37 Ce^+ dist
4285.54.....	1	1	n	.45 *Fe*
4285.91.....	1	1		.83 *Fe;* .01 *Ti*
4286.44.....	1	2	b, h, p	.44 *Fe;* .49 Zr^+
4286.74.....	1	— 1	v.n, real?	.....
4286.97.....	1	0	n	.99 La^+ dist; .98 *Fe*
4287.44.....	1	1	n	.41 *Ti.* Forbidden Fe^+ not required
4287.61.....	1	0	n, h	.58 *Fe*
4287.88.....	1	0	n, h	.89 Ti^+
4288.07.....	2	0	b, h	.00 Rb^+; .15 *Fe, Ti;* .01 *Ni*
4288.36.....	1	— 1	h, p	*Cr;* .4 Cs^+?
4288.65.....	1	— 1	p; B 249 } A 486	.65 *Mo;* .72 *Rh*
4288.80.....	1	3	} A 486	.80 V^+
4289.05.....	1	2	v.b, H; B 249 } A 486	.07 *Ti;* .95 Cs^+; .18 Zr^+; .96 *Fe*
4289.392.....	2	1	n, h } b, h, p	.36 *Ca* dist
4289.603.....	.....	5	} b, h, p	Setting on mean
4289.76.....	2	2	H } b, h, p	.73 *Cr* dist
4289.95.....	1	4		.92 *Ti;* .93 Ce^+ (each inten. 2±)
4290.127.....	1	4	} d? dif	.22 Ti^+; .12 *Ca*
4290.265.....	3	7	} d? dif	Mean
4290.370.....	1	3	} d? dif	.38 *Fe*
4290.51.....	1	3		.51 Pr^+
4290.732.....	2	2	h, indist	(.87 *Fe*)
4291.00.....	1	1	h	.93 *Ti*
4291.26.....	1	2	H	.21 *Ti*
4291.54.....	1	1	H, indist	.47 *Fe;* .56 *Ge*
4291.745.....	3	2	h	.83 *V;* .7 *Cl?*
4292.032.....	2	1		.98 *Cr;* .13 *Fe* Pred

TABLE IV—*Continued*

γ GEMINORUM PLATES B 236, B 249, A 486				LABORATORY
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4292.258	2	1		.28 *Mn*$^+$; .29 *Fe*
4292.51	1	2	n	
4292.78	1	5	h; ft comp. r not incl	
4292.973	2	0	v.n	.9 *Zn*
4293.089	1	1	H	.10 *Zr* ; .13 *Pr*$^+$?
4293.563	1	4	H	*Cr*; .59 *Pr*$^+$?
4293.912	2	3	n	.99 *Rb*$^+$ dist
4294.090	2	7	d, vi, ftr	Mean
4294.159	3	5	f	.13 *Fe*; .11 *Ti*$^+$. *Fe* prob more than 2/3 of total intensity
4294.486	2	1	n, h	.42 *S* ?
4294.775	2	1		.78 *Sc*$^+$
4295.046	1	0	n, prob real	.02 *Dy*
4295.21	1	1	h	
4295.50	1	1	?	
4295.593	2	1	b, d?	.61 *Ca*
4295.69	1	1	?	.75 *Ti*; .76 *Cr*
4295.954	2	1		.91 *Zn*$^+$; .05 *La*$^+$ dist; .07 *Ce*$^+$; .90 *Ni*
4296.25	1	0	n	.12 *V*
4296.436	2	3		
4296.530	3	3	h, prob d	.56 *Fe*$^+$; mean
4296.632	2	2		.68 *Ce*$^+$ dist; .74 *Zr*$^+$
4297.793	1	1	n	.72 *Ru*; .75 *Pr*$^+$
4298.425	1	— 2	H, indist	.4 *Zn*
4298.929	3	1		.99 *Ca* dist; .90 *Zr*
4299.138	2	2	h	.14 *Ti*; .24 *Fe*
4299.238	2	.....	d, merged	Mean
4299.432	2	1	h	.4 *Ce*$^+$; .4 *As*
4299.768	2	2	f	.7 *Cr*; .63 *Ti*
4300.036	3	8	blend	Mean
4300.061	1	8	H	.05 *Ti*$^+$ dist
4300.390	3	1		.33 *Ce*$^+$; .22 *Mn*$^+$
4300.522	1	1	h	.56 *Ti*. *Cs* not required for obs. inten.
4300.834	2	2	h	.83 *Fe*
4301.018	1	0	n	.08 *Ti*; .97 *Ca*; .10 *Nb*
4301.130	2	1	d? h	Mean
4301.244	1	0	n	.2 *Cr*; .32 *V*$^+$
4301.535	1	0	n, h	.54 *Ca*
4301.779	3	2	g	.78 *Zr*$^+$
4301.899	3	4	d	Mean
4302.001	3	2	g	.93 *Ti*$^+$; .08 *Bi*$^+$; .12 *W* distinctive
4302.457	1	1	d?	.53 *Ca* dist; .30 *Y*
4303.079	2	3		
4303.181	3	4	d, h	.18 *Fe*$^+$; mean
4303.348	2	2		
4303.576	1	0	v.n; real?	.59 *Ti*$^+$? .61 *Nd*$^+$ dist
4303.881	1	1	n	.80 *Er*$^+$?
4304.086	1	1	n	.1 *Cl*?

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4304.236	1	— 1	v.indist; B 249	
4304.381	1	0	H, def; B 236	.34 *Zn*$^+$; .47 *Nd*
4304.629	1	— 2	v.indist	.55 *Fe*
4304.985	1	— 2	H	(.0 *Ra*; .0 *K*; .14 *Ce*$^+$)
4305.367	1	1	h, f; B 249	.46 *Sr*$^+$ dist; *Fe*, *Ti*
4305.507	1	1	H; B 236	
4305.766	2	0	h, indist	.71 *Sc*$^+$; .80 *Pr*$^+$
4306.235	1	0	H, def	
4306.562	1	2	dif	.58 *Fe*; .73 *Ce*$^+$
4306.936	2	1	H	.0 *Cr*$^+$
4307.516	1	1	n	.59 *Ru*
4307.898	3	6	b, g	.86 *Ti*$^+$; .91 *Fe* dist; .74 *Ca* dist*
4308.300	1	1	*n*	.18 *Bi*
4308.422	1	1	sli. b, p	Mean
4308.570	1	1	H	.54 *Bi*
4308.926	2	0	n	.92 *Zr*$^+$; .02 *Sa*$^+$; .0 *K*
4309.169	2	0		.04 *Fe*?
4309.538	2	1	h, v. close d?	.38 *Fe*; .62 *Y*$^+$ dist
4309.752	1	0	p	.74 *Ce*$^+$
				Non-measurable lines
4310.76	1	— 2	H, indist	.78 *Fe*; .60 *Ir*
4311.012	2	1	b, H, dif	.06 *Mo*$^+$; .05 *Ag*$^+$?
4311.326	1	1		.32 *Nb*
4311.566	2	1	h	.66 *Mo*$^+$; .53 *Fe*; .65 *Ti*; .50 *Ir*
4311.817	1	1	h, prob real	
4312.654	1	2		.55 *Mn*
4312.875	3	5	seems d	
4312.913	1	3		.86 *Ti*$^+$; (.04 *Fe* Pred)
4313.349	1	— 2	p	.4 *Co*
4313.563	1	0	n	
4313.853	1	1	f	.9 *V*
4314.175	3	4	f	.12 *Sc*$^+$
4314.420	1	0	h, f; B 249	.34 *Ti*; .32 *Si*$^+$
4314.563	1	— 1	B 236	.50 *Nd*$^+$; .6 *Sb*
4314.846	1	— 1	v.n	.80 *Ti*
4315.010	3	4		.98 *Ti*$^+$; .09 *Fe*. *Fe* contributes 1/5±
4315.296	1	1	h	
4315.694	1	1	h	
4316.054	1	1	h	.05 *Gd*$^+$
4316.327	1	1	h, f	.22 *V*$^+$; .31 *V*
4316.888	2	2		.81 *Ti*; .96 *Yb*
4317.113	2	1	h	.16 *O*
4317.422	2	1	h	.31 *Zr*$^+$
4317.735	1	2	H	
4318.276	1	0	n	
4318.572	2	1	n	.63 *Ti*; .65 *Ca* dist
4318.844	2	0	n, h	.95 *Sa*$^+$; .85 *Tb*
4319.169	1	1	h	.1 *Sr* ?

* Approximate intensities: *Ti*$^+$, 4; *Fe*, 2; *Ca*, 1.

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4319.489	1	0	n, f	.46 *Fe* Pred.; .54 *Ca*
4319.783	1	1	H, p	(.65 *Cr; O*$^+$; .88 *Ru*)
4320.096	1	1	n, f	.98 *Er*$^+$
4320.374	1	0	n, h	.36 *Fe; Co; Se*
4320.716	2	4	d, merged	.75 *Sc*$^+$; .73 *Ce*$^+$; .6 *Cr*; .67 *Hf*$^+$
4320.790	3	6		.....
4320.940	2	2		.97 *Ti*$^+$; .88 *Ru*
4321.510	1	0	n, h	.54 *Ca*
4321.738	1	4		.66 *Ti*; .80 *Fe*
4321.990	1	1	n, h	.02 *V*$^+$
4322.212	2	0	h	.22 *Ti*
4322.500	2	0	n	.52 *La*$^+$
4322.762	2	0	n	.....
4323.014	2	0	n, h	.....
4323.234	1	— 2	v.n; B 249	.29 *Sa*$^+$
4323.390	2	0	h; B 236, B 249	.37 *Fe* Pred; .5 *Cr*
4323.734	1	0	n, h	.....
4324.015	1	0	H	.....
4324.523	1	1	n, h	.....
4324.780	1	0	H	.....
4324.984	2	1	b, H	.00 *Sc*$^+$; .95 *Fe*; .13 *Ti*
4325.529	3	2	d, merged	.36 *Ni*; .62 *Ni*
4325.704	3	5		.66 *Gd*
4325.815	3	3		.77 *Fe* dist; *Nd; O*$^+$; .82 *Tb*
4326.077	1	— 2	H, indist	.14 *Mo*
4326.405	1	— 1	n	.35 *Ti*
4326.626	2	0	h	.7 *Mn*$^+$; .76 *Fe*
4326.919	1	0	h	.....
4327.264	1	1	h	.1 *Gd*$^+$, *Fe*
4327.918	1	0	h, def	.0 *Mo*$^+$; .93 *Fe*; .93 *Nd*$^+$
4328.280	2	— 1	h, prob real	.43 *Bi*$^+$
4328.520	1	— 2	real?	
4329.050	1	1	half; B 249	.03 *Sa*$^+$
4329.226	1	1	H, dif	.22 *Ca*
4329.582	1	0	H	.55 *Fe* Pred
4329.880	2	0	H	.....
4330.173	1	1	h	.2 *Cs*$^{+?}$; .26 *Ti*$^+$
4330.4	.....	.....	not m, absorp	*Ce*$^+$
4330.813	1	— 1	b, H, dif	.71 *Ti*$^+$; *Ni*; .96 *Fe*
4331.439	1	— 1	h, p	.5 *Rb*$^{+?}$; .42 *Nb*
4331.642	2	0	n, h	.56 *V*$^+$; .64 *Ni*; .75 *V*$^+$
4331.941	1	1	h	.....
4332.269	1	1	n	.....
4332.654	1	0	n	.57 *Cr*
4332.86	1	— 3	h, u	.....
4333.143	2	0	n	.25 *Zr*$^+$
4333.512	1	....		.....
4333.586	2	— 1	H duplicity doubtful	.....
4333.699	1	....		.77 *La*$^+$ dist
4333.962	2	0	H, p	.98 *Pr*$^+$

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4334.402	2	0	n, h	.....
4334.722	2	0	h	.87 Ce^+
4335.077	1	0	H	.97 La^+
4335.324	1	− 1	h	.....
4335.683	1	2	h, f	.74 *Pr*
4336.059	1	2	n	.....
4336.326	1	1	n, curved	.25 Ce^+
4336.620	1	2	n, h, g	.62 *Fe* Pred; .65 Hf^+; .7 *As*
4337.017	1	2	b, H	.05 *Fe;* .86 O^+; .13 *Nh*
4337.411	1	− 1	sli.b, H; B 236	.4 *Mn;* .32 Ti^+
4337.580	1	0	B 249	.57 *Cr;* .60 Zr^+
4337.799	2	− 1	v. indist	.76 Ce^+
4337.869	1	0	B 249	.92 Ti^+
4338.039	1	0	B 236	.....
4338.347	2	0	b, p	.27 *Fe;* .44 *Tb;* .48 *Ti*
4338.623	1	− 1	n	.69 Pr^+; .71 Nd^+
4338.906	2	0	h, indist	.84 *Fe* Pred; *Mn*
4339.212	1	1	v.h	.2 *Fe;* .32 Ce^+
4339.658	2	1	f	.72 *Cr;* .53 Zr^+; .64 *Co*
4339.964	2	2		.03 Ti^+
4340.274	2	9	v.v.b; multiple appearance may be due to grain only	.....
4340.443	3	40		*Hγ*
4340.562	2	10		.6 Bi^+; .67 Ra^+
4340.782	1	10		.....
4340.926	1	0	h, grain bad; B 249	.....
4341.088	1	2	B 226	.....
4341.282	2	1	n, h	.37 Ti^+; .23 *Fe* Pred; .25 *Gd*
4341.534	1	1	n, f	.....
4341.891	1	− 1	v.indist	.....
4342.220	1	0	sli.b, h	.24 Zr^+; .18 Gd^+
4342.602	1	− 1		.....
4342.665	1	− 1	d? B 236	.....
4342.84	1	− 1		.85 *V*
4342.954	1	0	n, H; B 249	.....
4343.167	1	1		.18 *Cr;* .27 *Fe*
4343.631	1	1	def, p	.57 *Ce;* .70 *Fe; Cl*
4343.928	2	1	H	.02 Mn^+
4344.271	2	1	H	.29 Ti^+; .32 $Pr^{+?}$
4344.519	2	1	H two lines?	.51 *Cr*
4345.068	1	2	H	.09 *Cr*
4345.232	1	− 1		.....
4345.480	2	0	h	.57 O^+
4345.830	2	1	H	.87 Sa^+
4346.178	2	1	H	.11 *Ti*
4346.604	1	1	n, h	.56 *Fe;* .60 *Ti?*
4347.446	1	0	H, p	.43 O^+; .47 *Pr*
4347.866	1	1	n, f	.80 Sa^+; .85 *Fe;* .88 Zr^+
4348.300	2	1	b, h	.3 $Rb^{+?}$; .32 *Fe* Pred
4348.588	1	0	n	.43 Mn^+
4348.974	1	0	h	.94 *Fe*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4349.121	1	— 1	h	.....
4349.478	2	0	H	.44 *O*
4349.798	1	1	H	.79 Ce^+; .70 *Ru*
4350.014	2	1	H	.97 V^+
4350.330	2	— 1	H	.38 *Ba* dist; .34 *Mo*; .40 *Pr*
4350.654	2	1		.59 *Fe*; .73 *Ho*
4350.956	2	1	h	.84 Ti^+; .06 *Cr*
4351.303	2	0	h	.23 Nd^+; .38 O^+; .40 *Pr*
4351.636	2	2		.55 *Fe*; .60 *Nb*
4351.769	1	4		.77 Fe^+; .77 *Cr* may have inten. 1
4351.792	3	7	Practically merged	Setting on mean
4351.950	2	2		.94 *Mg* dist; .85 Pr^+
4352.151	1	0		.1 *Mg*; *Sa*; *A*
4352.378	2	0	H	(.2 *Sb*; .33 *Y*)
4352.686	2	2	n, h	.7 *Ce* dist; .74 *Fe*
4353.289	1	0	n, grain bad	.....
4354.356	2	— 1	n, H	.39 La^+
4354.711	2	— 2	H	.62 Sc^+; .76 *Fe*
4355.656	1	— 2	v.n, real?	.65 *U* dist; .7 *Te*
4355.911	1	— 1	n, seems real	.91 *Ni*
4356.150	1	— 2	n, seems real	.07 Mo^+; .1 *Cr*
4356.388	1	— 1	n, seems real	.....
4357.12	1	0	h	.15 *Fe* polar
4357.458	1	1	n, f	.52 *Cr*
4357.730	1	0	n	.72 *Y*
4358.092	1	1	n	.20 Nd^+
4358.268	1	1	h	.3 Mo^+; .34 *Hg* sensitive
4358.611	1	0	h	.51 *Fe*; .72 Y^+
4358.904	1	— 1	H	.....
4359.642	2	— 1	h	.6 Zn^+; .63 *Cr*; .74 Zr^+ dist
4361.122	2	0	H	.06 *Co*; .20 *Ru*
4361.527	1	0	H	.6 Ce^+
4362.081	1	0	b, H	.05 Sa^+; .10 Ni^+
4362.993	1	0	h	.98 *Pr*
4363.370	1	2	g	.3 $Cs^{(+?)}$
4363.642	1	0		.65 Mo^+
4363.852	1	1	H merged, p	.01 Y^+
4364.124	1	1	H merged, p	.17 Y^+
4364.414	1	2	half	Cs^+ ?
4364.779	1	0	v.n	.65 Ce^+ dist; .66 La^+
4365.182	1	— 1	n, h, real?	.3 Mn^+
4366.482	1	1	h, curved	.36 Nd^+; .45 *Zr*
4366.937	1	— 1	H, p	.95 V^+; .9 *As*; .91 O^+
4367.595	2	3	h	.66 Ti^+; .58 *Fe*
4367.656	2	4	d, h, merged	.....
4367.892	2	1	h	.906 *Fe*; .89 Hf^+
4368.206	3	1	H	.30 *Ni*; .33 Pr^+
4368.431	1	0	h, indist	.44 *Nb*
4369.333	1	0	H, p	.41 Fe^+; .28 O^+
4370.448	2	0	h, indist	.3 *Au* ?

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4370.764	1	0	n, h	.....
4371.00	1	— 3	p	.95 *Zr*$^{+}$ dist; .92 *Hf*$^{+}$
4371.150	2	0	h	.13 *V*$^{+}$ Pred; .2 *As;* .28 *Cr*
4371.577	3	— 1	H, p	.62 *Pr*$^{+}$
4371.754	1	0	def	.8 *Rb*$^{+}$; .7 *U* dist
4372.126	2	0		.21 *Ru*
4372.447	1	— 1	n	.33 *Si*$^{+}$; .38 *Ti*
4372.739	1	0	h, p	.....
4372.949	2	0	h	.99 *Fe;* .0 *Cs*$^{+?}$
4373.246	1	1	H, d width	.16 *Sa;* .26 *V* and *Cr*
4373.605	1	0	n, h	.57 *Fe;* .61 *Co;* .65 *Cr*
4373.829	1	1	n, g; B 249	.82 *Ce*$^{+}$; .81 *Pr*
4373.979	1	1	n, f; B 226	.....
4374.096	1	0	v.n, f; B 249	.17 *Cr*
4374.399	3	2	h	.46 *Sc*$^{+}$; .40 *Pr;* .50 *Fe*
4374.653	1	2	def	.....
4374.921	3	3	h	.83 *Ti*$^{+}$; .95 *V*$^{+}$ dist; .00 *Nd*$^{+}$; .82 *Rh*
4375.271	1	1	H, def	.33 *Cr, Dy*
4375.526	1	0	n, h	.44 *Ti?*
4376.014	2	0	H	.93 *Fe;* .92 *Ce*$^{+}$
4376.108	1	1	d? h	.....
4376.238	1	1	h	.....
4376.845	1	0	n	.78 *Cr* and *Fe*
4377.22	1	— 1	H, p	(.1 *Te;* .15 *Rb;* .34 *Fe* Pred)
4377.507	1	— 1	H, curved	.5 *Cr*
4377.766	2	— 2	H, indist	.76 *Mo*$^{+?}$; .80 *Fe*
4378.026	1	0	n	.90 *Nb;* .09 *La*
4378.295	2	— 2	indist	.23 *Sa*$^{+}$; .17 *Cu*
4379.251	2	0	h	.2 *Fe*$^{+}$; .24 *V* dist
4379.548	3	0	H	.55 *O*$^{+}$
4379.795	1	— 2	n	.74 *Mn*$^{+}$; .77 *Zr*$^{+}$ dist
4380.029	1	1	h, half	.07 *Co*
4380.459	1	0	h	.43 *Sa;* .5 *Fe*
4380.793	2	0	H, indist	.7 *Rb*$^{+?}$; .95 *Zn*$^{+}$
4381.174	1	0	H	.19 *Ca;* .12 *Cr*
4381.336	1	1	n	.3 *Mn*
4381.52	1	— 3	n, H, p; B 236	.....
4381.663	1	0	H, B 249	.66 *Mo* dist; .7 *Mn*
4381.878	2	— 1	h	.89 *Th* dist
4382.144	1	0	H	.17 *Ce*$^{+}$ dist
4382.439	1	1	n	.42 *Pr*$^{+}$
4382.578	1	.....	merged H	Setting on mean
4382.680	1	0	b, h	.78 *Fe;* .8 *Se; Pr*
4382.90	1	1	n, upper half	.93 *Ca;* .94 *Zr*
4383.09	1	1	n, lower half	.10 *Zr*
4383.518	3	7	g	.55 *Fe* dist; .45 *La*
4384.190	2	3	H	.13 *Pr*$^{(+?)}$; .3 *Sa*$^{+}$
4384.411	3	.....	merged	Setting on mean
4384.448	2	2	H	.....
4384.686	2	2	H B 236, B 249	.64 *Mg*$^{+}$; .73 *V* dist; .72 *Er*$^{+}$; 68 *Fe*

TABLE IV—*Continued*

γ GEMINORUM PLATES B 236, B 249, A 486				LABORATORY
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4384.73	3	.....		Mg^+, Sc^+ blend only
4384.831	1	2	H; A 486	.81 Sc^+; .85*W*
4384.961	2	— 1	H	.98 *Cr*; .04 Ag^+?
4385.357	3	4		.39 Fe^+; .38 *Ru*; .18 La^+
4385.642	2	— 1	h	.65 *Ru*; .68 Nd^+; .76 Zn^+
4385.984	2	1		*Pb*
4386.312	2	0	H, def, real?	.....
4386.584	1	2	h	.....
4386.808	1	2	h	.....
4386.892	3	2	H, d?	.858 Ti^+; .9 *Pb*; .84 Bi^+
4387.056	1	1	h	.....
4387.398	2	1	h	.5*Cr*
4387.79	2	— 1	H, real?	.....
4388.572	1	1	H	.....
4388.815	1	0	H, indist	.....
4389.255	1	1	h	.25 *Fe*
4389.627	1	1	n, h	.63 *Fe* polar; .7 *Mn*?
4389.931	1	1	h	.99 *V* dist; .86 *Ni*; .91 *Gd*
4390.564	3	3	b, d? H	.59 Mg^+; .44 *Ru*; .46 *Fe*; .69 *Nd*
4391.031	3	1	H	.98 Ti^+; .89 Sa^+; .12 Th^+ dist
4391.43	2	— 1	H	.47 Bi^+
4391.770	3	0	H, p	.76 *Cr*; .66 Ce^+ dist
4392.660	1	— 3	H	.57 *Fe* Pred
4393.035	1	0	H, def	.....
4393.189	2	— 1	H, def	.16 *Ca*
4393.564	1	1	n	.5 *Cr*; .6 *U*
4393.987	3	2	sli.b, H, prob d	.93 *Ti*; .06 Ti^+; .00 *Ca*; .02 Si^+
4394.397	1	0	H, p	.....
4394.722	2	— 1	H	.....
4395.022	3	5	g	.03 Ti^+ dist; .9 Mg^+; .02 Pr^+
4395.377	3	0	H	.24 *V* dist? .29 *Fe*
4395.772	2	1	n, h	.78 Pr^+
4395.830	2	2	on mean prob d	.85 Ti^+
4395.970	2	0	n, h	.95 O^+; .99 *Ca*; .07 Pr^+
4396.384	2	0	h	.....
4397.075	1	1	h	*Ni*
4397.5	.....	.....	not seen	*Gd*
4397.872	1	2	H, d? equal. B 249	(.79 *Ru*; .03 V^+) (98.31 Ti^+ absent)
4398.776	1	— 3	n	*Ni*
4399.054	1	— 2	n	.21 Ce^+
4399.418	2	0	h	.33 *Pr*; .48 *Ir*; .5 *Cs*
4399.768	3	3		.77 Ti^+
4400.403	3	1	H	.39 Sc^+
4400.674	1	0	h	.59 *V* dist; .63 Ti^+ Pred
4401.102	1	0	n, h	.1 *N*
4401.426	2	— 1	n, H	.4 $Rb^{+?}$; .33 Zr^+; .45 *Fe*
4401.640	1	— 1	H	.55 *Ni*
4402.242	1	— 1	v.n, real?	.3 *Yb* dist
4402.614	1	0	n	.55 *Ba* dist

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4403.3.....	1	tr?		.35 *Zr*$^+$
4403.633.....	2	— 1	H	*Cr*; .62 *Pr*$^+$
4403.885.....	1	— 1	H, def	.8 *Cs*$^+$?
4404.300.....	1	0	n	.28 *Ti*
4404.508.....	2	0	h close	.40 *Ti*
4404.794.....	3	3	close	.752 *Fe* dist
4405.044.....	2	— 1	H, p	.02 *Fe* Pred; .14 *Zn*$^+$
4405.26.....	1	— 3	v.p	.3 *Cs*$^+$?
4405.98.....	1	0	def, p	.84 *Pr*; .14 *Fe* Pred
4406.60.....	1	.....	defect?	.68 *Gd*; .65 *V*
4407.3.....	1	tr?		*Fe*
4408.330.....	2	0	n, h	.42 *Fe*; .21 *V*; .25 *Gd*
4408.5.....	2	.....	nothing seen	.52 *V* dist
4408.684.....	1	0	n, h	.....
4408.890.....	1	1	h	.83 *Pr*$^+$
4409.552.....	2	1	n	.54 *Ti*$^+$? Multiplet 30 absent?
4409.964.....	1	0	sli.b, h	.00 *Cs*$^+$; .03 *Ru*
4410.2.....	1	tr?	not m	.2 *Cs*; identical with .00?
4410.413.....	1	— 2	half	.50 *Ni*
4410.664.....	1	— 1	n, h	.6 *Ce* dist
4410.991.....	2	0	H	.9 *Cr*; .03 *Nd*$^+$; .08 *Ti*$^+$
4411.441.....	2	— 1	H	.5 *Sb*
4411.837.....	1	1	H	.71 *Mo*; .87 *Mn*
4411.98.....	2	.....	on mean merged, p	.*Ti*$^+$?
4412.179.....	1	0	H	.25 *Mo*$^+$; .17 *Pr*$^+$; .28 *Cr*
4412.538.....	1	— 1	def	.42 *Ti*; .62 *Sr*
4413.031.....	1	0	half	.1 *Zr*$^+$; .04 *Cd*
4413.564.....	2	1	H, p	.....
4413.585.....	1	1	on mean d	.....
4413.823.....	2	0	H, p	.77 *Pr*$^+$; .8 or .9 *Co*$^+$; *Cr*
4414.535.....	2	— 1	n	.54 *Zr*$^+$; .5 *V*
4414.821.....	1	— 1	H	.87 *Mn*; .89 *O*$^+$?
4415.080.....	1	2	n, h	.....
4415.144.....	3	2	mean d? H, indist	.13 *Fe* dist
4415.306.....	1	1		.2 *U* dist
4415.630.....	2	— 1	half; defect?	.58 *Sc*$^+$; .68 *Cd*
4415.806.....	1	1	h	.77 *Fe* Pred; .73 *Ta*
4416.077.....	1	1	half	.....
4416.356.....	2	1	H, p	.28 [*Fe* II]
4416.6.....	.....	tr?	not m	.61 *V*; .54 *Ti*
4416.822.....	2	5	g	.81 *Fe*$^+$
4416.948.....	1	2	n, H, ft, comp.v	.97 *O*
4417.259.....	1	— 1	n	.28 *Ti*; .35 *Hf*$^+$
4417.720.....	3	4		.72 *Ti*$^+$
4418.390.....	3	1	d?	.34 *Ti*$^+$; .43 *Fe*
4418.771.....	2	0	H, p	.78 *Ce*$^+$ dist; .67 *Th*$^+$
4419.176.....	1	— 1	n	.01 *Th*$^+$; .04 *Gd*$^+$; .1 *Cr*; .09 *Pr*
4419.612.....	1	— 2	H	.62 *Er*$^+$; .63 *Pr*
4420.5.....	.....	.....	nothing visible	.46 *Os*; *Sa*$^+$; .66 *Sc*$^+$
4421.258.....	2	0	sli.b, H, def	.23 *Pr*$^+$; .13 *Sa*$^+$; .27 *Gd*; .36 *Co*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4421.540	1	— 2	H	.58 *V*; .46 *Ti*
4421.914	3	1	H	.95 Ti^+
4422.292	2	0	sli.b, H, def	.....
4422.455	1	0	half; defect?	.44 *Gd*; .5 *V*
4422.618	2	0	H, p	.61 V^+ dist; .57 *Fe*; .7 *Cr*
4422.980	1	— 2	n, H	.98 *Ni*
4424.348	1	0	H, p	.35 Sa^+; .30 *Cr*
4425.470	1	0	H, indist	.44 *Ca* dist; .4 *Sb*
4426.037	2	1	H, p	.1 Rb^+; .05 *Ti*; .02 *V*
4426.333	1	— 1	H	.29 *Ir*
4426.771	1	0	h	.70 *Mo*; .77 *Er*
4427.16	1	0	d? merged	.10 *Ti*
4427.314	.....	.....		.312 *Fe*
4427.46	1	1		.56 La^+
4428.03	1	0	h	.00 Mg^+; .90 Ti^+ Pred; .92 Ce^+ dist
4429.32	1	.....	def	.23 Pr^+; .27 Ce^+; .3 *Fe*; .34 *Zr*
4429.818	2	— 1	h	.90 La^+ dist; *Cr*; .80 *V*
4430.152	1	— 2	n	.19 *Fe*
4430.640	2	— 1	b, H	.618 *Fe*; .7 Rb^+?; .5 *Cr*
4431.194	2	0	n	.14 *Ni*; .28 *Ti*; .35 Sc^+
4431.865	1	0	n	.91 *Ba* dist
4433.520	1	1	indist, p	.51 Mo^+; .5 *N*; .58 *Ti*
4433.762	1	1	H	.79 *Fe*; .91 Sa^+
4434.104	3	1	H	.0 Mg^+; *Ti*
4434.866	2	1	n, h	.96 *Ca* dist; .96 *Mo*
4435.632	2	— 1	H	.68 *Ca*; .54 Eu^+; .7 Cs^+?
4435.959	1	— 1	h; B 249	La^+
4436.115	1	— 2	prob real; B 236	.18 *Gd*; .22 Ra^+; .14 *V*
4436.279	1	— 2	H; B 249	.36 *Mn*
4436.549	1	— 1	H	.59 *Ti*
4436.838	1	— 2	h	.93 *Fe*
4437.14	1	— 2	half, p	.....
4437.575	1	— 2	h	*Ni*
4437.879	1	1	d? merged	.84 *V*
4437.945	1	1		.....
4438.056	1	0		.04 *Sr*, *Zr* ?
4438.435	1	0	H	.36 *Fe*
4439.487	1	— 2	H, dif	.52 *Ce* ?
4440.1	.....	tr?		.13 Rb^+?
4440.260	1	— 3	n, indist	*Fe*
4440.434	1	0	n	.44 Zr^+; .48 *Fe*; .35 *Ti*
4440.703	1	1	n; A 486	.....
4440.8	1	tr?	B 236	.84 *Fe*
4441.744	1	0	H, indist	.69 *V*
4442.100	1	.....	H	.....
4442.408	1	0	n, indist	.343 *Fe*; .42 *Ni*; .49 *Zr*
4443.028	2	— 1	h	.99 Zr^+ dist; .05 O^+
4443.34	1	— 3	v.n, half	.20 *Fe*?
4443.781	3	6	g	.80 Ti^+
4444.257	3	1		.22 *V*; .26 *Sa*; .27 *Ti*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4444.448	1	0	n, defect?	.40 *Ce*$^+$ dist
4444.600	2	1	h	.56 *Ti*$^+$; .70 *Ce*$^+$
4445.13	1	— 1	h, def	.07 *Co*; .20 *Zr*
4445.698	1	— 1	n	.....
4446.384	2	0	h	.37 *Nd*$^+$
4446.82	1	— 2	h	.84 *Fe*
4449.145	2	— 1		.14 *Ti*
4449.3	.....	.....	nothing seen	*Ce*$^+$, *Ru*
4449.606	1	1	n	.72 *Dy*$^+$
4450.016	2	0	h	.98 *Ti*; .87 *Pr*
4450.334	1	1	n	.24 *Pr*; .32 *Fe*
4450.489	3	2	d	.49 *Ti*$^+$
4450.608	1	1		.74 *Ce*$^+$; .77 *Fe* Pred
4450.96	1	— 3	H	.90 *Ti*
4451.22	1	— 3	H; B 236	.....
4451.510	1	2	sli.b, h; B 249	.58 *Fe*$^+$; .55 *Nd*$^+$; .59 *Mn*
4451.66	1	— 3	H; B 236	.....
4452.048	1	— 2	n, h	.02 *Nd*$^+$; .04 *V*
4452.444	1	— 2	h	.38 *O*$^+$
4452.716	1	— 2	H	.75 *Sa*$^+$
4453.106	1	— 1	n	.01 *Mn*
4453.285	1	tr		.32 *Ti*
4453.450	1	— 1	h	.....
4453.71	2	0	n; only tr on B 236	.71 *Ti*; .82 *Fe* Pred
4454.349	1	00	H	.383 *Fe*; .40 *Pr*$^+$
4454.770	2	— 2	H, indist	.78 *Ca* dist; .66 *Sa*$^+$; .80 *Zr*$^+$
4455.30	1	1	sli.b	.32 *Mn*; *Ti*
4455.690	2	0	h	.80 *La*$^+$; .82 *Mn*
4455.896	1	1	h; A 486	.88 *Ca*
4456.445	1	1		*Nd*$^+$; .34 *Fe*; .5 *Ca*
4457.002	1	0		.04 *Mn*
4457.338	2	— 1	H	.36 *Mo*; .41 *Zr*$^+$; .43 *Ti*
4457.547	2	0		.55 *Mn*; .48 *V*
4458.209	1	1	n	.10 *Fe*; .26 *Mn*
4458.445	1	0		.33 *Pr*$^+$; .53 *Cr*; .54 *Sa*$^+$
4458.915	3	0	h	.05 *Ni*
4459.137	1	1	d	.12 *Fe*
4459.203	2	0	h	.....
4459.645	1	0	n	.64 *Zr*; .78 *V* dist; *Cr*
4460.170	1	1	h	.20 *Ce*$^+$ dist; .31 *V*
4460.50	2	— 3	b, p	.50 *W*
4460.89	2	0	n	.8 *Cr*
4461.334	2	— 1	h	.21 *Zr*$^+$; .20 *Fe*; .4 *Fe*
4461.635	1	0	n, on B 236	.65 *Fe*
4461.790	1	0	H B 249	.82 *Fe* Pred
4462.18	2	— 2	H, doubtful	.1 *Fe*$^+$
4462.505	2	— 1		.46 *Ni*; .37 *V* dist
4462.805	1	0	n; B 249	.8 *Cr*
4463.04	2	— 2	H, p	.96 *Nd*$^+$ dist
4463.535	1	— 2	n	.41 *Ce*$^+$; .54 *Ti*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4463.838.....	1	— 2	n	.....
4464.298.....	2	1	H	.....
4464.482.....	2	1	d merged	.46 *Ti*+
4464.660.....	2	1	H	.68 *Mn; Cr;* .78 *Fe;* V
4465.098.....	2	— 1	H	.5 *Cr*
4465.532.....	3	0	H	.5 *V*
4465.794.....	1	0	n, h	.81 *Ti*
4466.147.....	1	0	half	.18 *Fe; Cr*
4466.341.....	1	0	half merged	.4 *Ni*
4466.526.....	1	0	half	.554 *Fe;* .55 *Gd;* .46 *Ca*
4466.750.....	1	0	half	.7 *K*
4467.103.....	1	— 1	h	.14 *Gd; Ba*
4467.511.....	1	1	H, prob d	.33 *Sa*+; .54 *Ce*+; .6 *Se; Cr*
4467.714.....	2	0	h, p	.76 *Ca?*
4468.134.....	1	0	n	.....
4468.498.....	3	3	g	.49 *Ti*+ dist
4468.694.....	1	— 3	n	.67 *Pr*
4468.961.....	1	— 2	n	.....
4469.370.....	2	— 1		.382 *Fe*
4469.7.....	.....	.....	ft absorp red and vi not m	.52 *Rb*+?; .57 *Co* dist; .8 *Cr*
4470.156.....	1	1	H	.14 *Mn*
4470.374.....	1	— 1		.3 *Zr;* .48 *Ni*
4470.698.....	2	— 1	H	.86 *Ti*+?
4471.028.....	1	— 2	sli. b, H	.23 *Ce* dist; .24 *Ti*
4471.385.....	1	0	H, indist	
4471.56.....	1	— 2		.57 *Co*
4471.705.....	2	— 2	h, d?	.68 *Fe* Pred
4471.75.....	1	— 2		.8 *Co*
4472.179.....	1	— 2	n, h	.....
4472.447.....	1	— 2	n, h	.4 *Sa*+; .34 *U*
4472.628.....	1	1	b, h, p	.54 *Fe* Pred; .72 *Ce*+; .71 *Fe*
4472.845.....	2	0	h, indist	.80 *Mn;* .93 *Fe*+
4473.335.....	1	— 1	h	.4 *Co*
4473.50.....	1	— 1	half	
4473.630.....	1	— 1	h	.61 *Pd*
4474.474.....	1	— 2	H	.4 *As;* .60 *Mo*
4475.368.....	1	0	H, def	.31 *Cr;* .3 *P*
4476.048.....	3	0	h	.02 *Fe;* .06 *Ag;* .08 *Fe*
4476.67.....	1	0	H, half, real?	.....
4477.01.....	1	— 1	H, real?	*Cr?*
4478.240.....	1	0	H	.3 *Co*
4478.49.....	1	— 3	doubtful	.47 *Ir*
4478.717.....	2	— 1	H	.66 *Sa*+; .74 *Mn*+; .79 *Gd*+
4479.134.....	2	— 1	H	.....
4479.496.....	1	0	H	.44 *Ca;* .36 *Ce*+; *Mn;* .61 *Fe*
4479.92.....	1	— 2	p	.89 and .97 *Al*++ ?
4480.288.....	1	— 1	H	.28 *Cr*
4480.784.....	1	0		.....
4481.214.....	3	10	g	.23 *Mg*+ dist; .26 *Ti* prob. inten. 1 or 2

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4481.844	2	0		.83 *A*
4482.07	1	1	d merged	.....
4482.112	1	1		.04 Zr^+; .17 *Fe*; .26 *Fe*
4482.504	2	1	h	.40 Ti^+ Pred
4483.40	1	— 3	n, doubtful	.32 *Gd*
4484.09	1	— 1		.9 Ce^+; .94 *Co*; .19 *W*; .23 *Fe*
4484.977	1	— 1	h	.96 *Ca*; .82 Ce^+; .01 *Ti*
4485.428	1	— 1	H	.44 Zr^+
4486.143	1	— 1	H, indist	.....
4486.622	1	— 1	H, indist	.....
4487.251	1	— 3		.27 *V*
4487.487	1	— 2		.49 *V*
4488.269	3	2	h	.32 Ti^+; .25 *Au* dist; .2 *N*; .14 *Fe*
4488.846	1	— 2	n; B 249	.90 *V*; .92 *Fe*
4488.951	1	2		
4489.150	3	3	d, on B 236	.21 Fe^+; .10 *Ti*
4489.268	1	1		
4489.606	1	— 1	h, p	.5 *Cr*; .74 *Fe*
4490.953	1	— 1	H, p	.....
4491.428	3	2	H	.40 Fe^+
4491.70	2	0	dif, p	.66 *Cr*; .62 *Bi*
4492.705	1	0	n, inclined	.66 *Nb*; .69 *Fe*
4493.136	1	— 1	n	.99 *Bi*; .08 *Tb*?
4493.459	2	0	H	.54 Ti^+
4494.175	1	1	n	.20 *Pr*; .05 *Fe* Pred
4494.588	1	0	H	.568 *Fe*; .6 or .4 Zr^+
4495.267	1	— 1	n, h	.3 *Cr*; .39 *Fe*
4495.681	1	1	n	.59 *Fe*
4496.159	2	0	h	.15 *Ti*
4496.449	1	— 2	h	.43 Pr^+
4496.871	1	0	H, p	.97 Zr^+ dist; .86 *Cr*
4497.440	2	0	H, p	.40 Co^+; .4 *V*
4498.224	2	0	H	.15 *Ru*; .26 *Gd*
4498.526	1	— 1	H	.60 *Fe* Pred
4498.7	.....	.....	not seen	.75 *Pt*; *Cr*
4498.954	1	0	h	.90 *Mn*
4499.638	1	1	H, p	.47 Sa^+
4499.939	2	— 1	h, dif, p	.96 *Zr*
4500.407	1	0	H	.29 *Cr*
4500.7	.....	tr?		.75 *Er*
4501.291	2	5	n, g blend	.27 Ti^+
4501.383	1	3		.....
4501.515	1	— 1	n, f	.5 Cs^+?
4501.765	1	0	n	*Cr*; .82 *Nd*
4502.203	1	— 2	H, p	.22 *Mn*
4502.532	1	1		.59 *Fe*
4503.279	1	— 1	H	.....
4504.238	1	— 2	n, seems real	.....
4504.570	1	— 2	n, seems real	.56 Cr^+ Pred
4504.805	1	— 2	n, seems real	.84 *Fe*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4505.39.....	1	— 3	def	.4 *K; Ti?*
4506.030.....	2	— 1	n	.94 *Ba* dist; .96 *Y*
4506.473.....	2	— 2		.42 *Ce*
4506.7.....	.....	.....	not seen	.7 Ti^+
4507.038.....	1	2	h, p	.11 *Zr;* .22 Cr^+ Pred too dist?
4507.854.....	1	1	half	.86 *Ca*
4508.250.....	3	4	h	.29 Fe^+
4508.98.....	1	— 1	h, half; B 236	.88 *Fe* Pred
4509.166.....	1	— 1	n; B 249	.14 *Fe* Pred; .18 *Ce;* .25 Ni^+
4509.731.....	1	2	H; A 486	.8 *Fe.* Inten. .0 on B 249
4510.098.....	1	— 2	u	.15 Pr^+; .2 Zn^+; .0 *In* dist
4510.390.....	2	— 1	H	.54 Th^+?
4510.823.....	1	— 1	H, p	.85 Rb^+; .75 Ag^+; .9 *N*
4511.198.....	1	0	n, H, p	.18 *Ti;* .31 *In* ultimate
4511.71.....	1	— 1	H, dif, p	.83 Sa^+
4511.9.....	.....	.....	not seen	.92 *Cr*
4512.248.....	3	— 1	h	.27 *Ca*
4512.66.....	1	— 1	inclined	.74 *Ti;* .54 Al^{++} ?
4512.88.....	2	— 2	real?	.83 Al^{++} ?
4513.310.....	1	— 1		.....
4513.812.....	2	— 1	n, h	.71 *Ti;* .72 *Fe* Pred
4514.178.....	1	2	H; A 486	.19 *Fe;* .14 *Pt*
4514.31.....	1	— 3	h; B 236	.....
4514.806.....	2	— 2	n, h	.8 Rb^+; N^+; Ag^+
4515.123.....	2	— 3		.11 Sa^+; .15 *Ny;* .18 *Fe* Pred
4515.354.....	3	3		.34 Fe^+
4515.687.....	1	1	n, g	.61 *Ti?* Multiplet weak
4518.364.....	2	0	H, p	.33 N^+
4519.103.....	2	0	h	.....
4519.357.....	1	— 2		*Co?*
4519.6.....	.....	.....	not seen; B 249	.64 Sa^+
4519.95.....	2	1		.85 *Cr;* .99 *Ni?*
4520.153.....	3	3	d merged	.....
4520.23.....	2	3		.24 Fe^+ (.36 Ti^+ Pred not indicated)
4520.825.....	3	— 1	h	.....
4521.160.....	2	— 1	n	.14 *Cr*
4521.439.....	1	— 2	n	.....
4521.601.....	1	— 2	n, real?	.....
4521.995.....	1	— 2	n, h	.96 *Ce;* .03 *Cr*
4522.203.....	1	— 2	indist, real?	.....
4522.413.....	1	1		.37 La^+ dist
4522.620.....	3	4		.64 Fe^+; .55 *Tm;* .56 *Eu*
4523.07.....	1	— 2	h, incl	.08 Ce^+; Sa^+
4524.006.....	1	— 2	v.u	.92 Sa^+; .10 *Fe*
4524.587.....	1	0	h	.....
4524.775.....	1	— 2		.74 *Sn* sensitive; .73 Ti^+
4524.977.....	1	— 2	v.dif, p	.95 Ba^+ dist
4525.280.....	1	0	n	.28 *La*
4525.761.....	1	— 2	n	.88 *Fe*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4526.308	2	0	h	.36 *Ti* multiplet 177?
4526.678	1	0	n	.7 Cs^+
4526.953	1	0	n, h, p	.98 *Ca* dist
4527.150	1	0	h	.25 *V* dist
4527.37	1	0	n, H } merged	.35 Ce^+ dist
4527.572	2	0	n, H }	.....
4528.153	1	0	n, H	.....
4528.46	1	1	def	.47 Ce^+
4528.616	1	1	n, h	.619 *Fe*; .55 V^+; .73 *Rh*
4529.133	2	−3	H, p	.18 Al^{++} ?
4529.455	2	0	dif	.49 Ti^+; .6 Al^+; .3 *V*; .4 *N*
4530.3	.....	.....	nothing m	.36 Rb^+?
4531.010	1	− 1	H	.99 *Co* dist
4531.585	1	.....		.64 *Fe*
4532.509	1	0	h	.....
4533.002	1	− 1	p	.02 *Zr*; .00 [*Fe* II]
4533.368	1	0		.25 *Ti*? Multiplet prob. absent
4533.931	1	4		.97 Ti^+ dist; .00 *Co*
4534.031	3	6	d on B 236	.....
4534.194	1	2		.17 Fe^+; .15 *Pr*
4534.511	1	− 2	n	.5 *Mn*; .57 N^+
4534.711	1	1	n	.78 *Ti*
4535.106	1	− 1	n	.07 N^+; *Cr*
4535.475	1	− 1	n	.58 *Ti*?
4535.786	2	− 2	n, h	.72 *Cr*; .74 *Zr* dist
4536.256	2	− 2	n, half	.....
4536.585	1	− 2	n	.5 Sa^+
4537.08	1	− 2	h	.....
4537.290	1	− 1	h	.22 *Ti*; .25 *Tb*
4537.625	1	− 2	h	.68 *Fe*; *V*
4538.903	1	− 2	H	.9 Cs^+?; *Fe*
4539.246	1	− 2	H	.3 ± *Cs* dist
4539.7	.....	tr	not m	.73 *Ce* dist; .7 Th^+; *Cu*; .8 *As*
4540.024	1	− 1	H	.04 *Gd*; .9 Cs^+
4540.776	2	1	h	.77 Rb^+?; .71 *Cr*
4541.487	3	3	sli.b, h	.52 Fe^+; .33 Fe^+
4542.180	1	− 1	indist, p	.22 *Zr*; .43 *Fe-Mn*
4542.612	1	1	indist, p	.60 *Nd* dist; .63 *Cr*
4543.569	1	− 3	n	.52 *W*; .64 *U* dist
4543.972	1	− 3	n	.96 Sa^+; .02 Ti^+
4544.710	1	− 2	v.indist	.69 Cr^+ Pred; .62 *Cr*; .69 *Ti*
4544.9	.....	.....	nothing m	.9 Cu^+; .96 Ce^+; .14 Ti^+
4545.354	2	− 2	h, dif, p	.40 *V*; *Cr*
4545.72	1	− 3	H, real?	.....
4545.943	1	− 3	n	.96 *Cr*
4546.194	1	− 2	n	.....
4546.585	1	− 2		.....
4546.879	1	− 2	h	.83 *Nb*; .94 *Ni*
4547.302	1	− 2	h	.23 *Ni*; .30 *Ru*
4548.066	2	− 1	h	.09 *Ti*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4548.459	2	— 1	n, h	.48 *Ir*; .54 *Pr*
4549.084	2	— 1		.0 *As*
4549.280	1	2	half	.....
4549.532	3	6		.63 Ti^+ dist; .48 Fe^+
4549.88	1	1	defect?	.....
4550.508	1	— 1	sli.b, H	.....
4550.901	1	— 2	H	.82 *Fe*
4551.590	2	0	h	.65 *Fe* Pred
4551.823	1	0	n, f	.8 *V*
4552.099	1	0	n	.12 Er^+
4552.358	1	— 1	H, p	.25 Ti^+ Pred; .42 *Pt*; .46 *Ti*
4552.687	1	— 3	sli.b, H, dif	.63 Sa^+; Si^{++}?
4553.979	3	1	h	.97 *Zr*; .04 *Ba* dist
4554.491	1	0	n	.44 *Sa*; .45 *Fe* ;.52 *Ru*
4555.044	2	1	h	.07 Cr^+; .12 *Zr*
4555.458	1	— 1	n	.3 *Cs* dist; .49 *Ti*
4555.880	3	3		.90 Fe^+; Cu^+
4556.40	1	— 3	n, h	.....
4556.76	1	— 2	def, p; B 236	.....
4556.976	1	— 1	H; B 249	.94 *Fe*
4557.429	1	0	H	.....
4558.003	1	0	H	.09 *Ti*; .11 *Fe*
4558.632	3	3	h	.66 Cr^+
4560.040	1	— 1	H	.93 *Ti*; .94 *Ni*; .10 *Fe*
4560.415	1	— 3	H, p	.42 Sa^+; .27 Ce^+ dist
4560.754	1	1		.72 *V*
4561.180	1	— 2	n, H	.15 *Bi*
4561.674	1	0	n	.....
4562.107	1	— 2		.....
4562.3	.....	tr	not m	.35 Ce^+
4562.5	.....	.....	nothing m	.5 Th^+
4562.98	1	— 3	H, p	.....
4563.777	3	4	g	.76 Ti^+ dist
4564.65	3	0	v.indist, p	.56 Ni^+; .59 V^+; .7 *N*; .72 *Fe*
4565.128	2	0	h, def	.....
4565.685	1	1	H	.61 *Co*; .68 *Fe*
4566.100	2	0	H, dif	.21 Sa^+
4566.542	1	— 3	H	.52 *Fe*
4567.122	2	0	n, h	.99 *Fe*
4569.3	.....	tr	not m	Co^+
4569.790	2	0	h	.....
4570.011	1	0	def, v.p.	.02 *Co*
4570.315	1	0	v.n	.....
4570.724	2	— 1		.66 *W*
4571.131	1	— 3	n, H	.12 *Mg* persistent
4571.474	1	0	n, half	.44 *Fe* Pred
4571.8	.....	.....	masked if present	.79 Rb^+ dist
4571.996	3	5		.97 Ti^+ dist
4572.3	.....	.....	masked if present	*Ce* dist; Pb^+
4572.676	1	.....	B 236	.69 *Be*

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4572.845	1	— 2	indist; B 249	.83 *Cr*$^+$ Pred
4573.229	1	— 2	indist	.09 *Nb*
4573.860	1	— 1	H, v.p	.88 *Ba*
4574.663	2	— 1	H	.72 *Fe;* .48 *Zr*$^+$ dist
4575.453	2	— 2	h	.4 *Ca;* .51 *Zr*
4576.379	3	2	H	.31 *Fe*$^+$
4576.913	1	0	h	.....
4577.2	.....	.....	nothing seen here	*V*
4577.498	1	— 1	H, p	.....
4578.528	1	— 2	v.n	.57 *Ca*
4579.047	1	— 1	h	.....
4579.562	1	— 2	h	.43 *Nb;* .66 *Ba*
4580.135	1	0	n, h	.06 *La*$^+$*;* .06 *Cr;* .13 *Co*
4580.4	.....	.....	nothing seen	.4 *V;* .47 *Ti*$^+$, multiplet v. weak
4580.955	2	1	h	.....
4581.568	1	0	H	.5 *Ca* dist; .52 *Fe;* .62 *Co;* .64 *Nb*
4581.853	1	2	b, h	.84 *Mn*
4582.211	1	— 1	H	.18 *V*
4582.840	3	2	H	.84 *Fe*$^+$
4583.802	3	6		.84 *Fe*$^+$
4584.446	2	— 1	n	.45 *Ru*
4584.798	1	0	H, p	.73 *Fe;* .83 *Fe;* .84 *Sa*
4585.012	2	— 1	h	*Cr*
4585.832	2	— 1	h	.82 *Al*$^+$*;* .91 *Ca* dist
4586.330	2	— 2	h	.2 *Cr;* .37 *V*
4586.90	2	— 2	indist	.00 *Cu*
4587.25	1	— 2		.14 *Fe*
4587.692	1	— 1	n	.....
4588.196	3	4	h	.21 *Cr*$^+$
4588.827	1	0	H	.9 *Ca*
4589.481	1	— 2	h	.35 *Dy*
4589.978	3	1		.96 *Ti*$^+$*;* .95 *Cr*$^+$
4590.526	2	0	def, p	.5 *Zr*
4591.075	2	— 1	h, p	.98 *O*$^+$*;* .23 *V*
4591.582	2	— 1	h, def	.44 *Cr?*
4592.055	3	2	h	.06 *Cr*$^+$
4592.37	1	— 3		.....
4592.634	1	1	sli.b, H	.655 *Fe?* .54 *Ni*
4592.87	1	— 3	h	.9 *Sc*
4593.207	2	— 1	H	.2 *Cs* dist
4593.406	1	— 3	p	.54 *Sa*
4593.72	1	— 3		.....
4594.04	1	— 3		.93 *Ce*$^+$ dist; .07 *Eu;* .10 *V*
4594.79	1	— 2	n, h	.9 *Ni*
4595.18	1	— 2	half	.15 *Mo;* .31 *Sa*$^+$
4595.75	1	— 2	b, H, p	.70 *Fe*$^+$
4596.81	1	— 2	doubtful; half	.90 *Co?*
4597.008	2	— 2	H, indist	.97 *Gd;* .06 *Fe* Pred
4597.689	1	— 1	n, H	.....
4599.031	1	— 2		.9 *Mn;* .09 *Ru*

TABLE IV—*Continued*

γ GEMINORUM PLATES B 236, B 249, A 486				LABORATORY
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4599.467	1	— 3	v.u	.5 *Sb*
4599.969	1	.....	H, indist, p	.90 *Fe;* .97 *W*
4600.276	2	— 1	H, indist	.22 V^+
4600.811	1	— 1	H	.75 *Cr*?
4603.301	1	— 1	n, h	.....
4603.837	1	— 1	h	.8 Cs^+; .7 *U* dist; .96 *Fe*
4604.35	1	— 2	H	.3 *Se;* .4 *Zr*
4604.74	1	— 2	H	.60 *Fe*
4604.967	2	— 1	h	.99 *Ni*
4605.15	1	— 2	H	.2 *U* dist; .25 *Fe*
4605.98	2	— 1	H, p	.....
4606.62	2	— 3	H, p	.62 *Er;* .76 *Nb*
4609.81	1	— 3	v.u	.88 *Mo;* .93 *W* dist
4611.412	1	— 1	b, H	.29 *Fe*
4612.75	1	— 3	n, H	.....
4613.21	1	— 3	n, H	.21 *Fe*
4613.46	1	— 2	v.u	.39 La^+; .34 *Cr*
4614.07	1	— 2	H, doubtful	.95 Zr^+
4614.55	1	— 2	H, p	.5 *Cr*
4614.97	1	1	n, h, p, real?	.....
4615.23	1	— 2	H, p	.20 *Ce?*
4615.52	1	— 3	b, H, indist	.43 Sa^+; .57 *Fe;* .70 Sa^+
4616.20	2	— 2	h, real?	.23 Ti^+; .27 Co^+
4616.618	2	1	H	.63 Cr^+
4617.156	1	0	n, h; B 249	.27 *Ti?*
4617.39	1	— 3	H, indist, B 236	
4617.664	1	0	h	.....
4618.078	2	0	H	.13 Sn^+
4618.746	3	3	H	.82 Cr^+; .76 *Fe;* .7 *Se*
4619.185	2	1	H	.29 *Fe*
4619.65	2	0	b, H	.53 *Ti;* .55 *Cr;* .68 *V*
4620.006	1	— 3	n, h	.86 La^+
4620.474	2	2	H	.52 Fe^+
4621.029	1	0	h, B 236	.....
4621.16	1	0	p, def, d? B 249	.....
4621.40	1	— 2	n, half, B 236	.51 Cr^+ Pred; .4 N^+
4621.723	2	— 1	h, dif	.70 *Ca*
4622.30	2	— 1	h	.45 $Rb^{+?}$; .47 *Cr*
4622.58	1	— 3	n, H	
4622.954	1	1	H	.....
4623.281	1	0	h	.....
4623.567	1	— 2	n	.....
4624.763	1	— 3	h	.90 Ce^+
4625.149	1	0	H, dif	.05 *Fe?*
4625.715	1	1	n	.77 *Co*
4626.137	1	0	n	.19 *Cr*
4626.84	1	— 1	H, indist	.79 *Fe* Pred
4627.017	1	0	n, inclined	.08 *U*
4627.326	1	— 1	n	.26 Eu^+
4627.869	1	1	h	.....

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4628.2	.....	.....	nothing seen	Ce^+ dist
4628.402	1	1	h	.33 *Ba;* .46 *Cr?*
4628.892	2	0		.75 Pr^+; *Co*
4629.293	3	3	b, H	.33 Fe^+; .34 *Ti;* .38 *Co*
4629.964	1	0	n	.88 *Zn*
4630.367	1	— 2	h, p	.....
4630.582	1	1	sli.b	.5 N^+
4630.883	1	— 1	n	.91 *Er*
4631.102	1	1	n	.04 *Fe* Pred
4631.588	2	0	h	.49 *Fe*
4632.144	2	0	h	.15 *Cr*
4632.547	2	— 1	H	.67 *Ca*
4632.888	2	0	n, h	.92 *Fe*
4633.318	2	— 1	h	.26 *Cr*
4633.606	2	— 1	H	.76 *Fe* Pred?
4634.049	2	3	b, h	.08 Cr^+
4634.665	1	0	n	.73 *Fe*
4635.222	2	2		.3 Fe^+?
4635.598	1	— 2	v.indist	.55 *Ti;* .62 *Fe* Pred; .67 *Ru*
4636.211	1	— 1	h, dif	.17 *V;* .35 Ti^+
4636.646	1	— 1	h, dif	.50 La^+; .63 *Gd*
4637.854	1	— 1	H, dif	.8 *Se;* .89 *Ti*
4638.275	1	— 1	H	.30 *O*
4638.431	1	— 2	n, h	.....
4638.84	1	— 3	n, H	.7 Na^+; .87 O^+; .9 *In*
4639.21	1	0	n, def one-third	.....
4639.68	1	— 2	n, H	.60 *Cr;* .67 *Ti?* .69 [*Fe* II]
4640.52	1	— 1	h	.60 *Er;* .6 N^{++}?
4640.94	1	— 1	H, p	.....
4641.16	1	— 1	H	.07 Ce^+; .26 *Ra*
4641.898	1	0	n, h	.83 *O;* .98 *Tb*
4642.2	.....	.....	nothing seen	.23 Sa^+
4642.45	1	— 1	H, p	.60 *Fe* Pred?
4643.58	1	— 2	v.indist, p	.69 *Y* dist; .47 *Fe;* .51 *Pr*
4645.882	1	0	n, h	.8 Nd^+; .0 *V*
4646.2	.....	.....	nothing seen	*Cr*
4646.5	.....	tr?	not m	Cs^+?; *Cr*
4647.037	1	— 2	H, dif	.0 Pr^+
4647.402	2	0	h	.44 *Fe*
4648.716	1	1	n	.66 *Ni;* .56 Rb^+?
4651.02	1	— 3		.12 *Cu*
4651.445	1	— 2	H	.51 Pr^+
4652.241	1	— 1	H	.16 *Cr*
4655.342	1	— 1	v.n, real?	.49 La^+ dist
4655.784	1	2	H	.69 *Ni;* .71 *Ti?* Inten. 0 on B 249
4656.690	2	2		.6 *In*
4656.955	2	1		.98 Fe^+
4657.130	1	1		.18 Ti^+
4657.442	1	— 1	H	.4 *Co; Mn*
4657.763	1	— 1	H	.....

TABLE IV—*Continued*

γ Geminorum Plates B 236, B 249, A 486				Laboratory
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4658.310.....	1	0	half, real?	.31 *Y*
4658.938.....	1	0	half, real?	.88 *Y*
4659.648.....	1	— 2	H	.....
4660.951.....	1	— 1	H	.....
4661.666.....	1	— 2	n, H	.54 *Fe*; .65 O^+; .77 Zr^+
4662.010.....	1	— 1	n, h	.90 Eu^+; .98 *Fe*
4662.364.....	1	— 1	H	.35 *Cd*
4663.152.....	1	— 1	H, dif	.05 Al^+; .19 *Fe*
4663.753.....	1	— 1	H	.71 Fe^+; .76 La^+ dist
4664.473.....	1	1	H, dif	Forbidden Fe^+?
4665.106.....	1	3	h; A 486	Inten. 0 on B 249
4665.499.....	1	— 1	b, d? dif	.44 *Er*; .54 Ni^+
4666.210.....	2	1	H	.2 *Cr*
4666.814.....	3	1	H	.75 Fe^+; .85 V^+
4667.200.....	1	— 1	H, real?	.2 N^+; .2 *Nb*
4668.846.....	1	— 2	h	.91 *La*
4669.4.....	.....	tr		*Sa*; *Ce*
4669.6.....	.....	tr		*Sa*
4670.366.....	1	1	h, f	.42 Sc^+; .3 Cs^+?
4671.163.....	1	— 1	H, dif, p	.....
4671.852.....	1	— 2	H	.81 *La*
4674.432.....	1	— 3	H, indist	.....
4674.6.....	.....	.....	nothing seen	*Sa*; *Fe* Pred
4675.00.....	1	— 3	H, indist	.....
4675.506.....	1	— 2	h	.6 *Ni*; .38 *Nb*; .61 Er^+
4675.981.....	1	— 1	def. real?	.....
4676.809.....	1	1	dif	.92 Sa^+; .9 *Ti*
4677.690.....	1	0	dif	.....
4678.037.....	1	— 1	n, h	.15 *Cd*
4678.938.....	1	0	b, H, dif	.852 *Fe*; .07 *Er*
4680.1.....	.....	tr?		*Zn* dist; Ce^+
4680.5.....	.....	tr?		*W* dist
4680.945.....	1	— 1	n, h	*Cr*
4681.456.....	1	— 1	n, h	.46 *Fe*
4682.054.....	2	0	n, h	.12 *Fe*
4682.513.....	2	0	n, h	.57 *Fe*; .33 V^+ too distant
4683.443.....	1	0	n	.43 *Zr*, .57 *Fe*
4683.809.....	1	— 2	h	.7 *Au*
4685.048.....	1	0	n	.0 *Ti*
4685.458.....	1	— 1	n	.....
4686.011.....	1	— 2	h	.....
4687.057.....	1	— 1	n	.....
4687.3.....	.....	.....	absorp not m	.20 Sa^+; .30 *Fe* Pred; .39 *Fe*
4687.617.....	1	— 1	inclined p	.....
4688.360.....	1	— 1	n	.39 *Ti*; .45 *Zr*
4688.869.....	1	— 2	H	.90 *Ce*
4689.521.....	1	— 2	H	.50 *Fe*
4690.292.....	1	— 1	H	.15 *Fe*; .38 *Fe* Pred
4691.189.....	2	— 2	H	.16 La^+
4691.824.....	1	0	h	.....

TABLE IV—*Continued*

λ GEMINORUM PLATES B 236, B 249, A 486				LABORATORY
Observed λ I.A.	No. of Plates	Inten.	Remarks	λ, Element, Etc.
4692.396.....	2	— 2	h	.49 La^+ dist
4693.071.....	1	— 2	sli.b, H	.0 *Sb*
4693.257.....	1	— 2	H	.19 *Co*
4693.787.....	2	— 2	h	.....
4694.302.....	2	— 1	h	.31 *Gd*
4696.782.....	1	— 2	H	.80 *Y*; .92 *Ti*
4698.167.....	1	— 1	n, h	.30 Sc^+
4698.567.....	1	— 2	n, h	.49 *Cr*; .62 *Cr*
4698.769.....	1	0	h	.74 Cr^+ Pred; .79 *Ti*
4701.240.....	1	0	H	.16 *Mn*; .35 *Ni*
4701.595.....	1	— 1	mod n, H	.54 *Ni*; .65 Al^{++}?
4702.112.....	1	— 3	H, p	.....
4702.973.....	2	2	h	.07 *Mg* dist; .03 Zr^+
4703.386.....	2	0	n	.....
4703.989.....	1	0	n, f	.....
4704.478.....	1	0	n, f	.40 Sa^+
4705.3.....	.....	tr		*Bi*; O^+
4706.388.....	1	— 2	n, h	.54 Nd^+
4707.029.....	1	— 2	n, h	.....
4707.589.....	1	— 2	n, h	.49 *Fe*; .52 *Pr*
4708.037.....	1	— 2	n, h	.04 *Cr*; .1 *Pr*
4708.483.....	1	— 2	appear merged, prob. due to lines between	.66 Ti^+
4708.838.....	1	— 2		.81 *Ca*; .97 *Fe*; *Ti*
4709.285.....	1	— 2		.09 *Fe*; .33 *Sc*
4709.996.....	1	— 1	H	.08 *Zr* dist; .04 O^+
4710.782.....	1	— 1	H, dif, def	.8 *Sb*; .9 *Zr*
4711.174.....	1	— 3		.....
4711.644.....	1	— 2	v.p, real?	.48 *Fe*; .8 *Sb*
4712.840.....	1	— 3	n, h	.91 La^+
4714.38.....	1	0	indist	.37 *Fe*; .42 *Ni* sensitive
4715.674.....	1	— 2	n, h, inclined	.58 Nd^+; .76 *Ni*
4722.75.....	1	1	H	.7 *Bi*; .5 *Bi* sensitive; *Cr*

— 1, — 2, and — 3 have been substituted for intensities oo, ooo, and oooo, respectively. The "Remarks," which were recorded at the times of measurement, refer to the character of the lines. The following abbreviations were employed:

absorp = absorption
b = broad
comp. r = companion on red side
comp. v = companion on violet side
d = double
def = defective
dif = diffuse
dist = distinctive
f = fair
ft = faint
ftr = fainter
g = good
h = hazy
H = very hazy
half = half-length
incl = included

indist = indistinct
m = measurable
mod = moderately
n = narrow
p = poor
prob = probably
s = sharp
sli = slightly
str = strong
tr = trace
u = uncertain
v = very
vi = violet

The identification of stellar lines with the elements which give rise to them is in large measure dependent upon relatively accurate positions as well as upon the more qualitative inferences drawn from laboratory data. In complex spectra, such as all but the simplest stellar spectra, interpretation is subject to future revision to the extent to which current theories will be modified and give way to new theories. However, the actual measures will probably have a more permanent value.

Considerable data were accumulated to aid in making decisions as to the components involved in blends. A preliminary study had shown that many of the prominent lines in the spectrum of γ Geminorum could readily be identified with singly ionized lines of *Fe*, *Ti*, and *Cr*. Evidently conditions in the atmosphere of γ Geminorum favor ionization. Consequently, all available lists of enhanced lines were drawn upon, supplemented by lists of the strongest lines appearing in the spark spectra of 48 elements. Also, such other lines were selected from the spectrum of each element as by inference from the actual and relative intensities in spark and arc and from the temperature classification seemed most likely to occur in the stellar spectrum if the element in question is represented at all. Lines which are weaker in sun-spots than in the sun are especially good prospects. Lists of spectroscopically classified lines, such as those by Russell, by Burns and Walters, and by others, proved particularly valuable in establishing identifications through multiplet relationships. The excellent paper by Dunham[1] on the spectrum of Alpha Persei, containing many spectral classifications not found elsewhere, proved very useful. Numerous other published lists of wave-lengths were consulted repeatedly, including Kayser's *Tabelle der Hauptlinien der Linienspektra aller Elemente*, the *Mount Wilson Revision of Row-*

[1] *Contributions from the Princeton University Observatory*, No. 9, 1929.

land's Preliminary Table of Solar Spectrum Wave-Lengths, and Twyman's *Wave-Length Tables* for its lists of the principal "distinctive" lines.

The last column of Table III contains laboratory data which in many instances establish the identifications of the observed lines with practical certainty. The elements are arranged in the order of decreasing importance in so far as this is known, the most important being given first. When the order of importance is not known, the elements are given in the order of increasing wave-lengths. In many cases the data given indicate merely the nearest laboratory lines to the observed stellar wave-lengths. This fact may often be inferred from general considerations based on modern theory. Thus, for example, it would seem that for elements with very low ionization potentials the arc lines, excepting "distinctive" lines, may be ruled out at once as improbable identifications. Similarly, lines which require very high excitation potentials, with an occasional exception like C^+, λ 4267, are absent. In most instances lines of this nature have been excluded from the last column. The recent analyses of laboratory spectra on the basis of the modified Bohr theory have proved so successful that the main features of the interpretations given must almost certainly continue to hold, no matter what the future may have in store for the theory itself.

In instances where most of the lines of a spectroscopically closely related group are apparently absent, identifications with one or two members of the group are to be regarded as uncertain. On the contrary, when the accordance with a classified group is good, both as to the observed positions and as to the relative intensities, the identifications may be regarded as established. A large number of examples of beautiful accordance could be cited, a few of which will suffice. Thus, strong "distinctive" 4395.0 is a member of Russell's Ti^+ multiplet No. 28, of which 4443.8 is of approximately the same intensity in laboratory spectra and in that of γ Geminorum, and 4450.5 is appreciably weaker in both. The seven lines of Fe ($1f^3 - 1g'^5$) run strikingly parallel in intensity in laboratory and star. The spectroscopic classification of the lines not only definitely established the identification of six of them, but for the seventh, 4294, it became at once evident that the stellar line was not due mostly or entirely to

Ti^+, as was at first supposed, but that its intensity is to be attributed about two-thirds to *Fe* and one-third to Ti^+. Thus, also, the stellar line 4315.0 can with assurance be assigned in major part to Ti^+ of $(1p^4-1d'^4)$, the *Fe* component belonging to the multiplet $(1p^5-1s'^5)$ being responsible for perhaps one-fifth of the total intensity of the blend. The stellar line 4549.5 is a blend of Fe^+, λ4549.48 and Ti^+, λ 4549.62. While a discussion of stellar and laboratory intensities of the multiplets of which these components are members indicate stellar intensities for them in about the ratio of 2 for Fe^+ and 4 for Ti^+, consideration of the observed wave-length of the blend would tend to equalize these intensities. For the star line 4589.98 the temptation is great to regard the Cr^+ component as unimportant, the Ti^+ component being of sufficient relative strength, judged by its multiplet relationship, to account for the entire stellar intensity.

However, it is somewhat disconcerting in tracing out multiplets to find some, like *Ti* $(1f^5-2d'^5)$, for instance, for which the stellar intensities do not follow the order of the laboratory intensities. Occasionally the discordance pertains to only a single line, as for 4320.95 of Russell's Ti^+ multiplet No. 36. Such identifications will probably prove to be not final or incomplete. There are a number of other seeming inconsistencies, as when a strong enhanced line, in some instances several enhanced lines at or close to a common wave-length, is either absent from the stellar spectrum or is represented by only a weak line. Something in the nature of the quenching effect, under the favorable conditions prevailing in the complex gas mixtures of the stellar atmosphere, may be responsible for many, and perhaps most, of these apparent discordances.

Of all the lines measured, $H\gamma$ is by far the strongest, followed by the enhanced magnesium doublet at 4481. Many of the other strong lines are enhanced. Adams and Russell found 77 per cent of the observed lines in Sirius (class A2) to be arc and only 23 per cent enhanced lines. In γ Geminorum the percentage of enhanced lines is somewhat increased. Of the 326 lines of intensity 1 or greater, 276 have been identified as being due in nearly equal proportions to ionized and neutral atoms. Included in the former are Fe^+, 27 lines; Ti^+, 36; Cr^+, 11; Sc^+, 7; Ce^+, 15; Zr^+, 7; Sa^+, 5; $Rb^{+?}$, 5; V^+, 4;

Mo$^+$, 4; *Mn*$^+$, 4; *Mg*$^+$, 3; and *Pr*$^+$, 3. Among the group of brighter lines due to the neutral atom are *Fe*, 42 lines; *Ti*, 17; *Cr*, 17; *Mn*, 9; *Ca*, 7; *V*, 5; and *Ni*, 4.

Other elements which have measured lines are *Al*$^+$, *Ba* and *Ba*$^+$, *La*$^+$, *Bi* and *Bi*$^+$, *Ni*$^+$, *Ru*, *Pb*, *Nd*, *Y*$^+$, *Cs*$^+$, *Eu*$^+$, *Sb*, and *Er*. *Pt*, *As*, *Os*, *Ho*, and *Yb* seem to be absent. *Gd*$^+$, *Zn*$^+$, *Te*, *Sr*, *Nb*, *Ir*, *Co*, *Ag*$^+$, *S*, and *Cl* proved more or less indeterminate, owing in part to the fact that their prominent lines are in coincidence with lines of other elements. When only a small number of lines of an element are available, a few such coincidences render a decision either difficult or impossible. For elements which are poorly represented by lines in the region of spectrum covered by the plates, an extension of the observations toward shorter and longer wavelengths is essential. Without question, a wealth of untouched material is awaiting an extension of stellar work, not merely to the immediately adjacent regions, but to the limit in the ultra-violet which could be reached by suitably chosen equipment and altitude of observing station.

About 80 of the so-called "distinctive" or "sensitive" lines are present, some of which are due to ionized elements. Of the lines of intensity 1 or greater due to the neutral atom, 27 are "distinctive." *Ca* is especially well represented, 5 of the 7 strongest *Ca* lines being included in this number. In fact, all of the 12 "distinctive" *Ca* lines listed in Twyman's tables are represented by measures.

The inference has been drawn that, because of its lower ionization potential, *Ti* should be ionized to a greater extent than *Fe* at the high temperatures prevailing in the atmospheres of class A stars, and consequently neutral *Fe* should predominate over *Ti*. This inference is confirmed for γ Geminorum. Among the lines of intensity greater than zero the measures include 42 *Fe* lines of mean observed intensity +1.8 and only 17 *Ti* lines of mean intensity +1.3, or two and one-half times as many *Fe* as *Ti* lines as well as a slightly higher average intensity. The significance of this preponderance of neutral *Fe* over neutral *Ti* is emphasized by the fact that the number of *Ti*$^+$ lines (36) exceeds those due to *Fe*$^+$ (27), and by the relative numbers of "distinctive" lines measured, which are as follows: *Fe*, 8; *Ti*, 1; *Fe*$^+$, 0; *Ti*$^+$, 7.

No appreciable relative displacements of lines seem to be present between Fe^+, Ti^+, and Cr^+, or between lines originating from different neutral atoms, or between those due to neutral and those due to ionized atoms. The very slight violet displacement of enhanced lines relative to arc lines indicated in Table V probably has no real significance.

TABLE V

TEST FOR SYSTEMATIC DISPLACEMENTS OF ENHANCED AND ARC LINES
(Observed λ—Laboratory λ)

ELEMENT	ENHANCED LINES			ARC LINES		
	Displacement	No. of Lines	Mean Intensity	Displacement	No. of Lines	Mean Intensity
	A			A		
Fe	−.017	25	+2.7	−.005	49	+ 0.3
Ti	−.011	27	+2.4	+.001	21	− .1
Cr	−.005	10	+1.4	−.009	14	+ .2
Sc	.000	8	+1.8			
Ca				−.016	28	+ .1
Ce	+.010	14	+0.4			
Sa	−.002	13	− .9			
La	−.004	9	− .9			
Zr	+.014	9	− .1			
V	+.023	3	+ .3	+.015	4	+ .8
Mn	−.016	5	+ .4	+.008	9	− .1
Rb	−.028	6	+0.2			
Ba				+.038	4	− 0.4
Hγ				−.02	1	+40.
Mg	.00	6	+2.7	+.010	2	− 0.5
Pr	+.008	5	+0.4			
Mo	−.025	4	+0.5	.00	1	0.
Bi	+.017	3	+1.0	+.03	1	− 2.
Mean (*a*)*	−.010	83	+2.1	−.002	101	+ 0.1
Mean of all	−.005	147	+1.2	−.004	134	+ 0.4

* Mean (*a*) is for elements represented in this table by both enhanced and arc lines.

The Bohr atomic theory, in spite of its beauty and wonderful success in completing known series, in predicting series which had been entirely unknown, and in harmonizing numerous previously unrelated facts, is still unsatisfactory in some important particulars. No theory will inspire confidence in having formulated ultimate relationships between the ninety-two known forms of elementary matter, which, except for the decomposition products of uranium and radium, merely allows of the possibility of breaking down an

element into something which has a structural resemblance to, but is not identical with, another element. With a number of secondary interrelations between the elements indicated, a more fundamental relation seems to be required, whether it be in the nature of an actual transmutation of one element into another or in the breaking-down of all the elements into one or more common, presumably identical, units of a lower order. In such a probability lie visions of possible future discoveries vastly greater than the combined discoveries of the past. Stellar spectra may be expected to contribute in large measure to a more satisfactory solution of the problem of the nature of matter.

It is a pleasure to express my indebtedness to Professor Frost for the use of the spectrograms; to the American Association for the Advancement of Science for a grant, a portion of which was used for the purchase of a daylight lamp; and to the Rumford Committee of the American Academy of Arts and Sciences for a grant to cover the cost of the Gaertner spectro-comparator.

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NOTES ON THE SPECTRA OF TEN BRIGHT-LINE STARS OF CLASSES B AND A[1]

By PAUL W. MERRILL

ABSTRACT

Among the stars whose spectra have been found at Mount Wilson to exhibit bright hydrogen lines are a number with peculiarities of special interest. Ten of these are here briefly described.

Peculiarities of special interest have been found at Mount Wilson in the spectra of more than twenty bright-line stars of early type. Descriptions of the following have already been published: H.D. 45910;[2] H.D. 51480;[3] DM. $-27^{\circ}11944$;[3] H.D. 53179, Z Canis Majoris;[4] B.D. $+14^{\circ}3887$;[4] H.D. 169515, RY Scuti;[5] H.D. 163181;[6] H.D. 45677;[7] H.D. 207757, B.D. $+11^{\circ}4673$.[8] A few others are being extensively observed and are reserved for future detailed discussion. For the ten remaining stars, for each of which there are two to thirteen spectrograms, it does not appear feasible to obtain long series of observations in the near future. These are briefly described in the present *Contribution*.

These ten stars (Table I) are among those in whose spectra bright hydrogen lines have been detected at Mount Wilson from objective-prism spectrograms of the *Hα* line. Data concerning all but the last, H.D. 218393, which has not previously been announced as having bright lines, will be found in *Contribution* No. 294.[9]

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 409.

[2] *Publications of the Astronomical Society of the Pacific*, **35**, 303, 1923. See also Plaskett, *ibid.*, p. 145, 1923.

[3] *Mt. Wilson Contr.*, No. 295; *Astrophysical Journal*, **61**, 418, 1925.

[4] *Mt. Wilson Contr.*, No. 334; *Astrophysical Journal*, **65**, 286, 1927.

[5] *Mt. Wilson Contr.*, No. 349; *Astrophysical Journal*, **67**, 179, 1928.

[6] Humason and Nicholson, *Mt. Wilson Contr.*, No. 353; *Astrophysical Journal*, **67**, 341, 1928.

[7] *Mt. Wilson Contr.*, No. 355; *Astrophysical Journal*, **67**, 405, 1928.

[8] *Mt. Wilson Contr.*, No. 381; *Astrophysical Journal*, **69**, 330, 1929.

[9] *Astrophysical Journal*, **61**, 389, 1925.

The plates designated by C in Tables II–XII were taken with a one-prism spectrograph attached to the 100-inch telescope; those by γ, with a similar spectrograph attached to the 60-inch telescope. An 18-inch camera was employed in both instruments, giving a dispersion at $H\gamma$ of about 35 A per millimeter. Unless otherwise

TABLE I

LIST OF STARS

H.D.	R.A. 1900	DEC. 1900	MAG.	SPECTRUM	
				H.D.	Mt. W.
29866	4^h37^m3	+40°36′	6.1	B5	B4ev
45995	6 25.6	+11 9	5.8	Bo	B2ev
160095	17 32.9	−33 29	8.7	B8	B8ev
163296	17 50.3	−21 56	6.6	Ao	A2ev
169454	18 19.6	−14 2	6.8	Bo	Boe
172694	18 36.5	−15 57	8.3	B3	Bep
180398	19 11.3	+12 56	7.7	B9	B(3)e
183143	19 23.0	+18 6	6.9	B	B9sea
195407	20 26.0	+36 39	7.7	B5	B(3)e
218393	23 2.6	+49 40	6.8	A5p	var

TABLE II

SPECTROGRAMS OF H.D. 29866

Plate	Date	Remarks
C 838	1920 Dec. 30	
C 855	1921 Jan. 5	
γ 11374	1922 Oct. 7	
C 2106	1923 Feb. 5	Region from $H\beta$ to Ha
γ 13216	1925 Jan. 13	
γ 13265	Mar. 1	
γ 14466	1926 Aug. 25	
γ 14760	Dec. 14	

noted, the spectrograms are of the usual blue-violet region. The G plates are of the yellow and red regions; these were made with a plane-grating spectrograph attached to the 100-inch telescope, and have a dispersion of 66 A per millimeter.

H.D. 29866

This spectrum is not particularly noteworthy except for small changes in the bright components of the hydrogen lines, described in the following notes.

On plates C 838 and C 855, $H\beta$, $H\gamma$, and $H\delta$ are broad, diffuse absorption lines with ill-defined edges. $H\beta$ is weak, as if partly filled with emission. Its width is about 16 A. The helium lines are weak and diffuse. *Mg* 4481 is weaker than *He* 4471. γ 11374 is a rather poor plate but shows no certain change. $H\alpha$ is a well-marked emission line on plate C 2106; $H\beta$ is about the same as on previous plates. Plates γ 13216 and γ 13265 exhibit small but decided changes in $H\beta$ and $H\gamma$; weak emission features appear within these

TABLE III

SPECTROGRAMS OF H.D. 45995

PLATE	DATE	$H\beta$, INTENSITY RATIO $Er:Ev$	RAD. VEL.	DISPLACEMENT Ev	
				$H\gamma$	$H\beta$
			km/sec.	km/sec.	km/sec.
C 728	1920 Oct. 26	1.0	+11	−84	.....
γ 11382	1922 Oct. 8	0.1	.....	31	−35
γ 11433	Nov. 5	0.0	.....	61	27
γ 11515	1923 Jan. 6	0.0	.....	59	27
γ 12154	Sept. 29	0.2	.....	83	65
γ 12502	1924 Feb. 19	0.3	31	77	64
γ 12509	Feb. 21	0.7	(13)	73	91
γ 12997	Oct. 8	0.6	51	96	73
γ 13138	Dec. 14	0.8	12	.....	−89
γ 13332	1925 Mar. 15	0.8	+17	−76	.....
Mean	.....	.....	+23	.....	.....
Faint companion					
C 840	1920 Dec. 30	Under-exposed	.....	.....	.....
C 3544	1925 Oct. 1	.....	+ 6	.....	.....

broad, dark lines. The violet emission component, *Ev*, is stronger than the red component, *Er*. The separation of the bright components is 4 or 5 A. On γ 14466, *Ev* and *Er* have nearly equal intensities. The spectrum appears much the same on γ 14760 as on the preceding plate, but the emission components are weaker.

H.D. 45995

This star is a double, β G.C. 3427: position angle 3°.8, distance 16″.3, magnitudes 6.0–8.2.

$H\beta$ consists of a weak, ill-defined absorption line on which are superposed two emission components of moderate intensity. On

certain plates these are run together; on others, distinctly separated. The average measured separation is 3.4 A. The violet component, *Ev*, remains of approximately constant intensity, while the other, *Er*, is decidedly variable. On the first plate and the last two, the components are of nearly equal intensity, but on several plates taken in 1922 and 1923 *Er* is weak or invisible. Table III gives estimates of the relative intensities. These suggest a period somewhat longer than five years.

$H\gamma$ resembles $H\beta$ except that the emission components are extremely weak. The average separation is 3.4 A, the same as at $H\beta$. *Er* is of variable intensity as in $H\beta$. The displacements of the violet emission components of $H\beta$ and $H\gamma$ are given in Table III. The displacements are smallest when the red component is very weak, apparently indicating a motion of *Ev* toward the center of the line. At $H\beta$ the effect might arise from a systematic error of measurement when both components are visible, but at $H\gamma$ the components are probably too weak and too well separated to produce such an error. The accuracy of the measurements is low, and small differences between various plates are without meaning.

The helium absorption lines are weak and diffuse and are thus unsuited for accurate measurement. It is therefore difficult to determine the radial velocity. The values given in Table III depend largely on the assumption that the central minima of the hydrogen lines occupy the normal positions of these lines. In several cases the helium lines give approximately the same velocities, but the measurements are scattering. K, measured on two plates, gives +18 km/sec.

The companion star is of type Ao. The mean velocity from six lines is +6 km/sec. The agreement of individual lines is poor.

Plaskett obtained seven spectrograms[1] of the brighter star (B.D.+11°1204) between October 28, 1922, and March 20, 1923, which showed "fuzzy absorption lines of helium and hydrogen with narrow sharp emission at $H\beta$ and $H\gamma$." This is in agreement with the Mount Wilson observations, for at that time the second emission component of $H\beta$ and $H\gamma$, *Er*, was invisible.

[1] *Publications of the Dominion Astrophysical Observatory*, **2**, 306, 1924.

H.D. 160095

On the first plate, $H\gamma$ is a strong, well-defined absorption line with a faint bright edge on the violet side. The measured distance between the centers of the bright and dark components is 2.14 A. $H\beta$ is somewhat similar except that the bright part is stronger and the absorption line much weaker. The measured distance between bright and dark components is 2.91 A. Weak absorption is probably present on the violet side of the bright portion of $H\beta$. This is not clearly seen at $H\gamma$. The principal dark components of $H\beta$ and $H\gamma$ agree in giving an apparent radial velocity of +25 km/sec. Seven dark lines of ionized iron give +35 km/sec., while *He* 4471 and *Mg* 4481 give a much larger value (see Table IV). λ 4481 is a broad

TABLE IV

SPECTROGRAMS OF H.D. 160095

PLATE	DATE	DISPLACEMENTS OF ABSORPTION LINES IN KM/SEC.			
		H	*Fe*	*He* 4471	*Mg* 4481
C 1776.....	1922 July 9	+25	+35	+110	+111
C 5246.....	1929 July 19	− 6	.....	.....	.....

line, but fairly well defined and measurable with reasonable accuracy; λ 4471 is weaker and more difficult to measure. The explanation of the decided difference between the displacements of these lines and those of iron and hydrogen is not obvious.

The second plate is underexposed, and $H\beta$ is the only line well shown. The absorption component is sharply defined and stronger than on the first plate, while the emission component is scarcely visible. The spectrum is weak toward the violet from λ 4400. $H\gamma$ can be seen, however, and is essentially an absorption line with no visible bright portion. Lines of iron, helium, and magnesium are not clearly seen and are probably weaker than on the other plate. This star may belong to that small group of Be stars which have α Cygni lines of variable intensity.

The difference in the measured displacements of the dark hydrogen lines on the two plates probably represents a real change in the position of these lines. The shift toward the violet exhibited by the

second plate as compared to the first is accompanied by the disappearance of the bright edge. This suggests that an underlying bright line serves as the background for an absorption line whose position varies. The phenomenon may be similar to that displayed by the long-period binary H.D. 33232, whose spectral variations will be described in a future *Contribution*.

H.D. 163296

On most plates $H\gamma$ is a wide dark line, which has, however, a narrow minimum measurable with fair accuracy. This minimum

TABLE V

SPECTROGRAMS OF H.D. 163296

PLATE	DATE	DISPLACEMENTS OF ABSORPTION LINES IN KM/SEC.				
		$H\gamma$	$H\beta$	*Mg* 4481	*Fe* and *Ti*	
C 1184	1921 July 26	− 91	−144	− 1	?	1*
C 2275	1923 May 28	−200	−209	+ 5	?	4
C 2287†	June 14	.....	.....	.....	.....	.....
γ 12581	1924 Apr. 18	(−100)	− 99	−21	−20	5
γ 12668	May 20	− 36	− 77	−15	12	5
Hilger 25	1925 May 17	.....	.....	.....	.....	.....
γ 15059	1927 June 17	−150	−178	+ 2	9	3
γ 15947	1928 July 5	+ 13	+ 12	+ 5	?	3
C 5193	1929 May 23	− 46	−119	− 2	− 7	3
Mean	.....	.....	.....	− 4	−12	.....

* Number of lines. † Red region.

usually lies toward the violet from the center of the line; in fact, on several plates $H\gamma$ might be described as a narrow dark line having a broad indefinite wing extending toward longer wave-lengths. $H\beta$ is similar to $H\gamma$, except that within the wing on the red side of the minimum is a portion which tends to be bright. The structure of $H\gamma$ and $H\beta$ is variable. Table V gives the measured displacements of the narrow minima; these vary through a large range and suggest a period somewhat less than four years. Plate C 2287, although underexposed, shows $H\alpha$ to be bright.

Mg 4481 is a well-marked dark line, rather wide but with fairly definite edges. On several plates it appears to have hazy bright borders. Its displacement (Table V) is probably constant within the error of measurement. A few enhanced lines of iron and titanium

are faintly seen. They yield nearly the same displacement as the magnesium line. Thus we have variable hydrogen lines accompanying metallic lines which exhibit little or no change.

Plate Hilger 25 was taken with a small ultra-violet spectrograph. It shows the unsymmetrical structure of $H\gamma$ and $H\delta$. $H\epsilon$, $H\zeta$, $H\eta$, and K are strong dark lines, probably of normal strength for class A2.

H.D. 169454

$H\beta$ consists of a dark line having a bright border on its red edge. $H\alpha$ is similar except that the bright portion is much more intense.

TABLE VI

SPECTROGRAMS OF H.D. 169454

PLATE	DATE	DISPLACEMENTS OF ABSORPTION LINES IN KM/SEC.					
		$H\gamma$	$H\beta$	He	O II	N II	Si III
γ 10413..	1921 Aug. 23	(−138)	−142	(+ 9) 3*	+10 7*	.....	+ 3 3*
C 1259..	Aug. 25	110	138	+20 4	+20 20	.....	+19 3
γ 10984..	1922 Apr. 13	(38)	142	− 5 3	+10 7	.....	+ 3 3
γ 10988..	Apr. 14	59	139	−21 5	− 2 8	.....	.....
γ 11075..	May 16	(80)	157	(+18) 3	+ 5 17	.....	(−23) 3
C 2195..	1923 Apr. 7	.....	133	+19 3	+20 7	.....	+22 3
γ 11911..	June 30	(60)	178	.....	− 7 17	.....	(+12) 3
C 2749..	1924 Apr. 17	(58)	139	−33 2	0 7	.....	− 8 3
γ 12698..	June 11	62	126	−14 5	− 2 16	.....	− 7 3
γ 12974..	Sept. 17	.....	126	(−31) 4	− 6 5	.....	−27 3
γ 14487..	1926 Aug. 29	− 53	−134	(+11) 4	+11 11	.....	− 9 3
G 360..	1930 Apr. 16	.....	.....	.....	.....	.....	.....
G 379..	Apr. 19	.....	.....	.....	.....	.....	.....
Mean..	.....	− 72	−141	− 4	+ 5	(+13)	− 1

* Number of lines.

TABLE VII

MEAN DISPLACEMENTS OF HYDROGEN LINES IN KM/SEC.

	$H\gamma$	$H\beta$	$H\alpha$
Emission.....	.....	+ 63	+ 47
Absorption....	−72	−141	−159
Em−Abs.....	.....	+204 (3.3 A)	+206 (4.5 A)

$H\gamma$ appears wholly dark, but is displaced toward the violet, probably by a rudimentary bright line on the red side. The measured displacements of the effective centers of the dark portions of $H\beta$ and $H\gamma$ are found in Table VI. Additional data are given in Table VII.

Both bright and dark components of the Balmer lines are evidently displaced from the normal positions. The dark lines grow relatively stronger in passing from $H\alpha$ to $H\gamma$ and their centers show smaller displacements. The bright line, on the other hand, gives at $H\alpha$ a smaller displacement than at $H\beta$, presumably because the relative intensity of the absorption is less.

The spectrum is notable for the prominence of the lines of *O* II. About twenty are measurable on the best plates, while several, including λλ 4254, 4317, 4319, 4345, 4349, 4366, 4414, 4416, 4639, 4642, and 4650, are conspicuous. The lines of *Si* III also are strong. The spectrum resembles that of χ^2 Orionis, but the *N* II lines are less intense and the *O* II lines slightly more intense.

The measured displacements of the lines of several elements are in Table VI. The lines, while of fair quality for measurement, are not particularly sharp, and the results for individual lines are rather scattering. The radial velocity derived from the lines of *He*, *O* II, and *Si* III is about zero. A few *N* II lines give +13 km/sec., which may agree within error of measurement. The line *Mg* 4481 is weak and the measures unreliable; the mean displacement from six plates is −28 km/sec.

Measurements of the $H\alpha$ line on the grating plates G 360, 379 are in Table VII. The dark helium lines 5876 (D_3) and 6678 are considerably displaced toward the violet. D_3 may have some emission on the red edge. The following lines are probably present: *Al* III 5696.47, 5732.65; *Si* III 5739.62; *N* II 5941.67. There is an unidentified line near λ 5780. The sodium lines D_1 and D_2 are strong and well defined. They give a mean displacement of −7 km/sec., corresponding to a residual velocity (after subtraction of the solar motion) of +7 km/sec., and are probably detached.

This spectrum has several interesting features which would probably repay more detailed study.

H.D. 172694

$H\beta$ and $H\gamma$ are sharply defined absorption lines with emission on the violet edge. Weak emission on the red edge of $H\beta$ may vary in intensity. Changes have not been noted in other features of the spectrum. The helium lines, wholly dark, are strong and well de-

fined. λ 4549 *Fe* is a narrow, weak, dark line. Its presence causes confusion as to the spectral classification. The mean displacements of the principal lines measured are as follows: *Hγ*, +40 km/sec.; λ 4471 *He*, +57; λ 4549 *Fe*, +58; *Hβ*, +58. The agreement of the last three is very close, although the individual values have considerable spread. The systematic relative displacement of *Hγ* does

TABLE VIII

SPECTROGRAMS OF H.D. 172694

Plate	Date	Rad. Vel.
		km/sec.
γ 10358	1921 Aug. 14	+49
γ 11922	1922 July 3	62
γ 12692	1924 May 25	54
C 3347	1925 June 15	+60
Mean		+56.1

not have an obvious explanation. Measurements of *Hγ* were given half-weight in computing the apparent radial velocities in Table VIII. If these results correspond to the actual radial motion, then the residual velocity, +70 km/sec., is abnormally high for a B-type star.

H.D. 180398

TABLE IX

SPECTROGRAMS OF H.D. 180398

Plate	Date
C 1319	1921 Sept. 18
C 2890	1924 July 19
C 4417	1927 Sept. 9

Hγ, *Hδ*, and *Hε* are broad, ill-defined absorption lines. *Hβ* is complex with weak emission superposed on a hazy, dark line. The emission is most distinct on the first plate; on the second it is very weak but clearly double; while on the last plate its presence is doubtful. The helium lines, wholly dark, are faint and diffuse.

An objective-prism plate taken September 5, 1921, shows the bright *Hα* line much more distinctly than others taken July 6 and 28, 1927.

The bright lines probably decreased in intensity from 1921 to 1927.

H.D. 183143

On the Mount Wilson spectrograms the dark hydrogen, helium, and silicon lines are generally strong and narrow; *Hβ*, however, is abnormally weak, and on plate C 4482 scarcely visible, probably

TABLE X

SPECTROGRAMS OF H.D. 183143

Plate	Date	Rad. Vel.	Remarks
		km/sec.	
C 1320.....	1921 Sept. 18	+12.3	
C 1932.....	1922 Oct. 7	.....	Red region
C 1940.....	Oct. 8	.....	Red region
γ 11389.....	Oct. 10	14.4	
C 2420.....	1923 Sept. 1	.....	Red region
γ 12821.....	1924 July 21	13.4	
C 4482.....	1927 Oct. 14	6.8	
C 4848.....	1928 June 18	.....	Includes red region
G 366.....	1930 Apr. 17	14.1	
G 375.....	Apr. 18	+16.1	
Mean....	.....	+12.8	.....

because the absorption is nearly balanced by emission. *Hα* is a bright line of low intensity. λ 4471 and λ 4481 form a pair of unusually well-defined lines. The spectrum must have been quite different on the plates used for the Harvard classification, as the *Henry Draper Catalogue* states: "The spectrum appears to be nearly continuous."

On the grating plates *Hα* is seen in emission. The following lines are dark: *He* 5876, 6678; *Si* II 6347, 6371; *Na* 5890, 5896, together with several unidentified lines of which the following are the most important: 5780, 5796, 5944, 6283, 6613. The first of these is near the silicon line 5780.38, but this line is of low intensity in the laboratory and has been ascribed by Fowler[1] to the spectrum of the neutral atom; hence its identification with the stellar line is improbable. Several atmospheric lines are known near λ 6283, but these do not seem sufficiently intense or in quite the right positions to account for the line in the spectrum of H.D. 183143. The identifi-

[1] *Philosophical Transactions of the Royal Society*, A, **225**, 41, 1926.

cations of these lines will be further studied when additional data become available.

The radial velocity exhibits no large variation from its mean value +12.8 km/sec. The largest residual is given by plate C 4482, but this does not clearly exceed errors of measurement. As far as present data go, therefore, we may consider the velocity constant.

The sodium lines, which are strong and well defined, give a mean velocity of +3.4 km/sec. The correction for solar motion is +18.4 km/sec., giving a residual velocity of +21.8, which is high for detached lines. The lines are abnormally strong for the spectral type of the star, however, and may be blends of stellar and detached lines. The H and K lines of calcium are also strong. Their displacement, measured on plate C 4482, is −11 km/sec., but this determination unfortunately has low weight. These lines require further observation.

This star is abnormally red for one of class B9. Viewed on the reflecting slit of the spectrograph, it has an orange tinge like a K-type star. Miss Burwell has carefully compared its spectrum with others of various types on several objective-prism plates taken with the 10-inch telescope from 1920 to 1927. She finds that the ratio of the intensity of red light to that of the blue-violet light is very nearly the same as for the spectra of Ko stars. The color-curve, however, does not appear quite identical with that of a Ko star, but may be slightly higher in the green and the ultra-violet. The color index determined on July 3 and 4, 1930, by Dr. B. W. Sitterly with the 10-inch telescope is +1.3 (international system). This is approximately the value for a giant G7 star.[1]

Several features of this spectrum are very interesting and merit further investigation.

H.D. 195407

Hβ is a bright line with a narrow central minimum. At *Hγ* the bright portions are fainter than at *Hβ*, and the dark center is stronger; it would more naturally be described as an absorption line with bright borders. At *Hδ* the bright borders are not seen. On the first plate the bright portions of *Hβ* and *Hγ* are stronger and the dark centers weaker than on the 1924 plates, among which slight varia-

[1] Seares, *Mt. Wilson Contr.*, No. 226; *Astrophysical Journal*, **55**, 165, 1922.

tions probably occur. The behavior may be somewhat similar to that of ϕ Persei. The average separation of the bright components of $H\gamma$ is 3.1 A, of $H\beta$ 4.0 A. The spectral type is not well defined and may vary.

TABLE XI

SPECTROGRAMS OF H.D. 195407

Plate	Date	Rad. Vel.
		km/sec.
C 1327	1921 Sept. 19	−68
γ 12596	1924 Apr. 21	82
γ 12688	May 24	(Underexposed)
γ 12726	June 15	82
C 3072	Nov. 8	−66
Mean		−74

The radial velocities depend largely on the hydrogen lines, but the lines of helium and iron, although very weak and seldom measured, appear to yield approximately the same results. The residual velocity, −57 km/sec., is high for a B-type star. Detached H and K, measured on plate C 3072, give the velocity −15 km/sec., corresponding to the small residual velocity +2 km/sec.

H.D. 218393

Hα was suspected to be bright on an objective-prism spectrogram taken with the 10-inch telescope on November 18, 1920, by Mr. Milton Humason.

The following remark occurs in the *Henry Draper Catalogue:* "The lines are very narrow, and the intensities resemble those in the spectrum of α Cygni, H.D. 197345."

On the Mount Wilson spectrograms the hydrogen lines are variable in structure and intensity. $H\gamma$ is chiefly a dark line, but on a few plates it has a distinctly bright edge toward the red. $H\beta$ consists of a broad, hazy, dark line with a double bright line of moderate intensity centrally superposed. The relative intensities of the two bright components change considerably. Their average separation is 3.92 A. On the grating plates G 21 and G 273, *Hα* is a very intense emission line with a narrow, nearly central, reversal.

The similarity to α Cygni noted by Miss Cannon is exhibited by

certain Mount Wilson plates, particularly γ 11288 and γ 13157, more strongly than by others. On these plates the α Cygni lines are conspicuous, while on γ 12988 they are but faintly visible.

The measured displacements of the absorption lines of various elements are given in Table XII. Most of the lines are not sharply defined, and the accuracy of measurement is not great. The helium velocities depend largely on λ 4471. *Si* II lines at λ 4128 and λ 4131, measured on four plates, give a mean displacement of +61 km/sec. Three *Ti* II lines on plate γ 13157 give +72 km/sec.; one line on

TABLE XII

SPECTROGRAMS OF H.D. 218393

PLATE	DATE	DISPLACEMENTS IN KM/SEC.			
		H	*He*	*Mg* 4481	*Fe* II
γ 11288	1922 Sept. 1	(+22)	−74	+66	+51
γ 11312	Sept. 27	−13	+ 1	+25	+38
γ 11961	1923 July 25	−18	+21	+11	.....
γ 12965	1924 Sept. 15	− 3	− 5	+26	+27
G 21	Oct. 3	.....	.....	.....	.....
γ 12988	Oct. 7	−26	−34	+15	−32
γ 13095	Nov. 11	−11	−32	−56	−27
γ 13157	1925 Jan. 4	+21	−62	+54	+71
C 3348	June 15	−29	−44	+ 3	(−33)
G 273	1929 Oct. 10	.....	.....	.....	.....

plate C 3348 gives −40. In general the results appear scattering and difficult to interpret. Rather large errors of measurement are doubtless present, but the more outstanding discrepancies must be due to actual changes in the effective displacements of the lines. Comparison of the data of Table XII with the intensities of the α Cygni lines suggests that when these lines are strong they have large positive displacements, while the helium lines have negative displacements.

The very strong K line, measured on plate C 3348, gives a displacement of −20 km/sec. The strong D lines on the grating plates give a mean displacement of −27 km/sec. These lines may or may not be detached. We hope to make later a more complete investigation of several features of this spectrum.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
June 1930

A METHOD FOR DETERMINING THE DISTRIBUTION OF STELLAR ABSOLUTE MAGNITUDES FROM THE DISTRIBUTIONS OF PARALLACTIC MOTIONS AND RADIAL VELOCITIES[1]

By GUSTAF STRÖMBERG

ABSTRACT

The paper outlines a method for deriving the distribution of absolute magnitudes within a group of stars from the distributions of the reduced v-components of proper motions and of the radial velocities. The method is similar to that developed in *Contribution* No. 395, which was based on the distribution of τ-components.

Mount Wilson Contribution No. 395[2] outlines a method for determining the distribution of stellar absolute magnitudes from the distributions of reduced τ-components and radial velocities. A similar method has now been developed for the parallactic motions and is described in the following pages.

The proper motion of a star projected on a great circle passing through the star and the antapex, counted positive toward the antapex, is the parallactic motion or the v-component of the proper motion. It is expressed in seconds of arc per year and may be regarded as the sum of two angular velocities: a component due to the reflection of the sun's motion relative to the group of stars studied and the component of the peculiar velocity in the direction of the antapex. If the distance R to the star is known, we can convert the angular motion into a linear velocity. The relation

$$kRv = V_0 \sin \lambda + \epsilon \qquad (1)$$

then holds. In this equation v is the v-component, V_0 the sun's velocity relative to the group—which is numerically the same as the group motion relative to the sun; λ is the angular distance from the sun's apex, ϵ the linear peculiar tangential velocity in the direction of the v-component, and k a constant depending on the units

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 410.

[2] *Astrophysical Journal*, **71**, 163, 1930.

employed. If R is expressed in parsecs and the linear velocities in km/sec.,

$$k=4.738 \text{ km year/sec.} \tag{2}$$

The absolute magnitude M, the apparent magnitude m, and the distance R are connected by the relation

$$M=m+5-5 \log R , \tag{3}$$

where M is defined as the apparent magnitude at a distance of 10 parsecs. Eliminating R between equations (1) and (3), we find

$$10kv10^{0.2(m-M)}=V_0 \sin \lambda+\epsilon=\mu_1 . \tag{4}$$

In this equation v, m, and λ are known for the individual stars. From the radial velocities we can determine the group motion V_0 and the distribution of peculiar radial velocities V', which, under certain conditions, are statistically comparable with the velocities ϵ.

Before proceeding farther we must consider existing correlations. There is a strong correlation between v and μ_1, between M and ϵ (correlation between absolute magnitude and average velocity), between V_0 and ϵ (correlation between solar motion and velocity dispersion due to the asymmetry in the velocity distribution), and between ϵ and λ (since the peculiar velocity of a star is a function of the direction of motion), besides indirect correlations arising from those just mentioned.

If the stars are so numerous that within the spectral range studied they may be subdivided according to M—by means of a criterion which need not be accurate—and also according to sin λ, we may simply take the logarithms of both sides of equation (4) and, writing

$$\left.\begin{aligned} x&=\log v+0.2m=\log v' , \\ y&=\log \mu_1-\log k-1 , \\ M'&=0.2M , \end{aligned}\right\} \tag{5}$$

obtain the fundamental equation

$$x=M'+y , \tag{6}$$

where M' and y may be regarded as independent since the range in M is limited.

These formulae are very similar to those used in *Contribution* No. 395, but there are some important differences. One is that the distributions of positive and negative v and μ_r, respectively, are not similar, as are those of positive and negative τ and V', respectively. The number of negative values of v and μ_r is, of course, in general smaller than the number of positive values. But a positive or negative value of v must correspond to a positive or negative value, respectively, of μ_r, whatever the distance or absolute magnitude of the star.

We might discuss the positive and negative values separately, but usually the number of stars in the group studied is too small for a separate analysis of the negative values. Instead, positive and negative values have been grouped together, which means that all have been regarded as positive. This is permissible since the numerical change in μ_r with change in M is the same for positive and negative parallactic motions. The distributions used are therefore superpositions of the distributions of positive and negative parallactic motions.

In limiting ourselves to the two zones for which $\sin \lambda$ has the same value, we must also limit the radial velocities used to determine the distribution of ϵ to two corresponding zones. The direction of the tangential linear velocity ϵ in equation (4) is the same as that of the peculiar radial velocity V' for a star situated 90° from the proper-motion star and on the same great circle, apex—star—antapex. Hence, deriving the distribution of y, we use the distribution of radial velocities for stars in two zones, one of which has an angular distance from the apex of λ plus or minus 90°, according as λ is smaller or larger than 90°, while the other is at the same distance from the antapex.

When the distribution of ϵ has been found, we can easily derive numerically the distribution of $\log |V_0 \sin \lambda + \epsilon|$ and of y, the vertical bars here and in the following indicating that the signs are disregarded. The method for combining several independent distributions is given in *Contribution* No. 395.

In most cases, however, the stars are not numerous enough for a subdivision according to both M and $\sin \lambda$. We then combine stars of different values of $\sin \lambda$; but since λ is known for each star, we can

reduce the dispersion in x by dividing with sin λ. We thus find from equation (4)

$$\frac{10kv10^{0.2m}10^{-0.2M}}{\sin\lambda}=V_0+\frac{\epsilon}{\sin\lambda}=\mu_2\,. \tag{7}$$

It is clear that small values of sin λ cannot be used; sin $\lambda>0.5$, that is, $30°<\lambda<120°$, has been found to be a practical limit. This excludes stars around the apex and antapex, but the areas involved are together only 13 per cent of the whole sky.

Taking the logarithms of both sides of equation (7) and introducing the new variables,

$$\left.\begin{aligned} x&=\log|v|+0.2m-\log\sin\lambda\,,\\ y&=\log|\mu_2|-\log k-1\,,\\ M'&=0.2M\,,\end{aligned}\right\} \tag{8}$$

we have as before

$$x=M'+y\,. \tag{9}$$

The method for determining the distribution of y depends on whether or not there is an appreciable correlation between ϵ and sin λ. The distribution of $\epsilon/\sin\lambda$ is statistically equivalent to that of $V'/\cos\lambda_1$, where λ_1 is the distance of a radial-velocity star from the apex, the signs of V' and of cos λ_1 being disregarded. We have here also to exclude stars for which cos λ is small; and if we limit ourselves to stars for which cos λ_1 is numerically larger than 0.5, we utilize only half of the sky. A somewhat smaller limit is thus advisable.

If the correlation between ϵ and sin λ is inappreciable, we may derive separately the distribution of $\epsilon=V'$ and of sin λ; and to find the distribution of y we combine numerically the two probabilities and use the value of V_0 for the particular range in absolute magnitude.

The correlation between $|\epsilon|$ and sin λ for the proper-motion stars is the same as that between $|V'|$ and $|\cos\lambda|$ for the radial-velocity stars. A glance at the scatter diagram will often tell if any appreciable correlation exists.

If no correlation between $|V'|$ and $|\cos\lambda|$ exists, we may simply

form the distribution of V' from all the radial-velocity stars within the spectral range, and also derive the group motion V_0 and the average radial velocity θ for different groups of absolute magnitude. The combined distribution of V' can then be adjusted to conform to the different values of θ by assuming that the corrections to the distribution of V' are the same as those of a normal error distribution when the dispersion is varied.

The following formula is easily derived:

$$\frac{dF(\epsilon)}{F(\epsilon)}=\left(\frac{\epsilon^2}{\sigma^2}-1\right)\frac{d\sigma}{\sigma}, \tag{10}$$

where σ is the dispersion in the error function.

Complete equivalence between the distributions of V' and ϵ is difficult to realize, in particular when the stars have a strong galactic concentration. If this concentration is very great, the equivalence may be good as far as motion parallel to the galaxy is concerned; but we cannot directly determine the distribution of radial velocities which would correspond to angular motions perpendicular to the galactic circle, since the number of stars at the pole of the galaxy is insufficient for this purpose.

The method for finding the logarithmic distribution for very small values of the variables is given in *Contribution* No. 395 for the case of a distribution which is constant in the neighborhood of zero. In the present case the distribution is not constant near zero, but it can be shown that the formula given also holds for a linear variation in the neighborhood of zero values. For any variable z we therefore assume

$$F(z)dz=k(a_0+a_1z)dz \quad (-\delta<z<\delta). \tag{11}$$

Denote the number of z-values numerically less than δ by n, and we find

$$k=\frac{n}{2a_0\delta}.$$

Thus

$$F(z)dz=\frac{n}{2\delta}\left(1+\frac{a_1}{a_0}z\right)dz.$$

Integration between $-z$ and $+z$, z being numerically less than δ, gives

$$\int_{-z}^{+z} F(z)dz = \frac{nz}{\delta}.$$

Regarding now all z's as positive and defining a new variable y by the equation

$$y = \log |z| + a_2,$$

we find the relation

$$\int_{-\infty}^{y} F(y)dy = \frac{n}{\delta} 10^{y-a_2}, \tag{12}$$

which is valid for $y < \log \delta + a_2$.

The derivation of the distribution of M' is made in exactly the same way as for the τ-components. An approximate distribution of M' is assumed and combined with the distribution of y to form an expected distribution of x. From the differences between the observed and expected distribution of x, corrections to $F(M')$ are derived by a least-squares solution. The process is repeated until a satisfactory reproduction of $F(x)dx$ is obtained.

CARNEGIE INSTITUTION OF WASHINGTON
MOUNT WILSON OBSERVATORY
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THE DISTRIBUTION OF ABSOLUTE MAGNITUDES AMONG M STARS BRIGHTER THAN THE SIXTH APPARENT MAGNITUDE AS DETERMINED FROM PARALLACTIC AND PECULIAR VELOCITIES[1]

By GUSTAF STRÖMBERG

ABSTRACT

1. The distribution of absolute magnitudes among M stars brighter than the sixth apparent magnitude has been determined from the distributions of parallactic and peculiar reduced proper motions and the distribution of radial velocities. The methods used are described in *Mount Wilson Contributions* Nos. 395 and 410. The number of proper-motion stars used is 247, and of radial-velocity stars 292.

2. The distribution of absolute magnitudes shows two distinct groups: supergiants with a maximum frequency at absolute magnitude -4.5 and ordinary giants around magnitude zero. The groups are separated by a clear gap around absolute magnitude -3.0. The relative proportions of stars in the two groups are 9 and 91 per cent, respectively.

3. Numerical values are given which will enable one to compute the mean absolute magnitude from the mean apparent magnitude and the mean of the logarithms of the τ- or v-components.

Mount Wilson Contribution No. 395[2] describes a method for determining the distribution of absolute magnitudes from the distribution of angular and linear peculiar velocities. In *Contribution* No. 396[3] the method was applied to the K and M stars brighter than the sixth apparent magnitude. *Contribution* No. 410[4] gives a similar method for the parallactic motions. This method, however, is somewhat more complicated, since both angular and linear parallactic motions depend on the position of the star and the computation is affected by the existence of several correlations. The method for parallactic motions has also been applied to the M stars brighter than the sixth apparent magnitude, and the results of an analysis of both the parallactic and the peculiar motions are given in this paper.

All stars in the *H.D. Catalogue* classified as M type and brighter than the sixth apparent magnitude were included in the study. To these were added some stars classified as M type by the Mount

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 411.

[2] *Astrophysical Journal*, **71**, 163, 1930.

[3] *Ibid.*, p. 175, 1930.

[4] *Astrophysical Journal*, **72**, 111, 1930.

Wilson observers. The list of radial velocities includes some stars down to the seventh apparent magnitude, but since these stars were not selected on the basis of large proper motion, their radial velocities can still be regarded as representative for the group studied, particularly since the effect of absolute magnitude is separately determined.

The proper motions were taken from Boss's *Catalogue*. H. Raymond's[1] corrections to the proper motions in declination have been applied. The v- and τ-components were computed from the equations

$$\left.\begin{aligned} v &= \gamma_1\mu_1+\gamma_2\mu_2 \,, \\ \tau &= \gamma_1\mu_2-\gamma_2\mu_1 \,, \\ \gamma_1 &= \frac{A}{\sqrt{A^2+B^2}} \,; \qquad \gamma_2 = \frac{B}{\sqrt{A^2+B^2}} \,, \\ A &= x_0 \sin\alpha - y_0 \cos\alpha \,, \\ B &= x_0 \cos\alpha \sin\delta + y_0 \sin\alpha \sin\delta - z_0 \cos\delta \,. \end{aligned}\right\} \qquad (1)$$

The proper motions in right ascension (great circle projection) and declination are here denoted by μ_1 and μ_2, respectively; x_0 and y_0 are proportional to the components of the solar motion in the equatorial system of co-ordinates. A constant apex of $\alpha = 270°$, $\delta = +30°$ is assumed throughout. That this apex may not be the best obtainable for the stars studied and may vary for the different absolute magnitudes, is of no importance as long as we use the same apex for both proper motions and radial velocities. The number of proper-motion stars used was 247; and for each of these the quantity $x_1 = \log|\tau| + 0.2m$ was computed, in which the vertical bars indicate that the signs are disregarded. After rejecting the stars within 30° of the apex and the antapex, 210 stars remained, for which the quantity $x_2 = \log|v| + 0.2m - \log\sin\lambda$ was derived, λ being the angular distance from the apex. The distributions of x_1 and x_2 were then derived, the interval used being 0.1. All values of x_1 and x_2 less than -1.7 were combined in one group and then redistributed according to the method described in *Contributions* Nos. 395 and 410. Apart from their effect on the smallest values of τ and v, the accidental errors have an entirely negligible influence on the distributions.

[1] *Astronomical Journal*, **36**, 129, 1926.

The radial-velocity stars used were 292 in number. For 250 of these, spectroscopic absolute magnitudes were available. The stars were collected in four groups according to the spectroscopic absolute magnitude. Table I shows the group motion V_0 and the average residual velocity θ. The increase in group motion with absolute magnitude is noticeable, but not large, as is also the increase in θ with M, although the supergiants seem to have abnormally large peculiar velocities.

The next step was to find if any correlation exists between ϵ (linear peculiar tangential motion) and sin λ. This correlation is the same as that between $|V'|$ (peculiar radial velocity without regard to sign) and $|\cos \lambda|$. A scatter diagram for the latter quantities showed no appreciable correlation; in fact, the value of θ for $|\cos \lambda| > 0.5$ is 17.8 km/sec., and for $|\cos \lambda| < 0.5$, θ is 17.6 km/sec. It was

TABLE I

M Spec.	No.	V_0	θ
		km/sec.	km/sec.
$\leqq -0.6$.....	41	20.1	17.4
-0.5 to -0.3.....	41	21.0	16.3
$-$ .2 to 0.0.....	102	23.3	17.6
$+0.1$ to $+0.6$.....	66	23.2	20.6

therefore possible to derive the distribution of $y = \log |V_0 + \epsilon/\sin \lambda| - 1.6756$ from the distributions of ϵ and of sin λ. Estimates of absolute magnitude based on spectroscopic determinations and reduced total proper motion were made for each star, and appropriate values of V_0 were used to derive the peculiar radial velocities V'. The combined distribution of V' for all the M stars together was determined. Small corrections to this distribution based on the values for θ in Table I were then derived to represent the velocity distribution for the different absolute-magnitude groups. Four distributions of V' were thus found which were supposed to be identical with those for ϵ. Finally, the distributions of y were derived by combining the probabilities of ϵ with those of sin λ, with the aid of appropriate values of V_0 for the four groups of absolute magnitude.

The second and fifth columns of Table II give the results for the observed distributions of x_1 and x_2, respectively, reduced to a total

TABLE II

x	$F(x_1)dx$		O−C	$F(x_2)dx$		O−C
	Obs. Dist.	Comp. Dist.		Obs. Dist.	Comp. Dist.	
−4.0	0	0.1	− 0.1	0	0.0	0.0
−3.9	0	0.2	− 0.2	0	0.0	0.0
−3.8	0	0.2	− 0.2	0	0.1	− 0.1
−3.7	1	0.3	+ 0.7	1	0.1	+ 0.9
−3.6	0	0.3	− 0.3	0	0.1	− 0.1
−3.5	0	0.3	− 0.3	0	0.1	− 0.1
−3.4	0	0.3	− 0.3	0	0.3	− 0.3
−3.3	0	0.3	− 0.3	1	0.3	+ 0.7
−3.2	1	0.5	+ 0.5	0	0.4	− 0.4
−3.1	0	0.8	− 0.8	0	0.5	− 0.5
−3.0	1	1.0	0.0	1	0.5	+ 0.5
−2.9	1	1.0	0.0	1	0.5	+ 0.5
−2.8	1	1.3	− 0.3	1	0.8	+ 0.2
−2.7	1	1.8	− 0.8	1	1.1	− 0.1
−2.6	1	2.2	− 1.2	2	1.3	+ 0.7
−2.5	2	2.7	− 0.7	2	1.6	+ 0.4
−2.4	2	3.5	− 1.5	2	2.0	0.0
−2.3	3	4.5	− 1.5	3	2.3	+ 0.7
−2.2	4	5.5	− 1.5	4	3.1	+ 0.9
−2.1	4	6.9	− 2.9	5	3.8	+ 1.2
−2.0	6	8.5	− 2.5	6	4.8	+ 1.2
−1.9	8	10.5	− 2.5	8	6.0	+ 2.0
−1.8	9	12.9	− 3.9	10	7.6	+ 2.4
−1.7	16	16.2	− 0.2	29	10.0	+19.0
−1.6	32	20.3	+11.7	2	13.1	−11.1
−1.5	26	25.0	+ 1.0	21	16.6	+ 4.4
−1.4	14	30.1	−16.1	21	20.3	+ 0.7
−1.3	43	35.6	+ 7.4	31	24.6	+ 6.4
−1.2	37	41.1	− 4.1	19	29.5	−10.5
−1.1	61	46.5	+14.5	40	35.1	+ 4.9
−1.0	39	52.0	−13.0	43	40.8	+ 2.2
−0.9	87	58.5	+28.5	36	45.4	− 9.4
−0.8	69	67.6	+ 1.4	50	51.2	− 1.2
−0.7	117	76.4	+40.6	48	60.1	−12.1
−0.6	77	82.4	− 5.4	52	69.9	−17.9
−0.5	43	84.5	−41.5	79	79.6	− 0.6
−0.4	79	80.0	− 1.0	95	87.1	+ 7.9
−0.3	79	69.3	+ 9.7	79	88.1	− 9.1
−0.2	49	55.6	− 6.6	74	81.7	− 7.7
−0.1	37	41.6	− 4.6	95	70.8	+24.2
0.0	34	26.7	+ 7.3	43	57.1	−14.1
+0.1	8	14.8	− 6.8	67	40.5	+26.5
+0.2	4	6.5	− 2.5	19	23.7	− 4.7
+0.3	0	2.4	− 2.4	9	11.3	− 2.3
+0.4	4	0.9	+ 3.1	0	4.3	− 4.3
+0.5	0	0.2	− 0.2	0	1.4	− 1.4
+0.6	0	0.1	− 0.1	0	0.4	− 0.4
+0.7	0	0.0	0.0	0	0.1	− 0.1
+0.8						

of 1000 stars. No smoothing has been done except, of course, below the limit -1.7. The computed distributions of x_1 and x_2 are given in the third and sixth columns, respectively. These were derived from the last approximation for the distribution of absolute magnitude, which appears in Table IV, combined with the distribution of

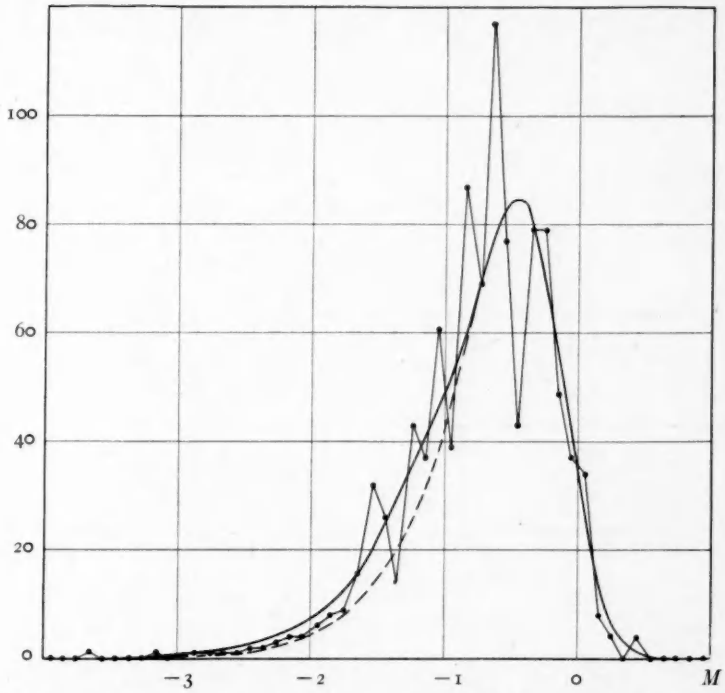

FIG. 1.—Distribution of $x_1 = \log \tau + 0.2m$ for stars of spectral type M. The dots joined by straight lines represent observed numbers within intervals $dx = 0.1$. For $x < -1.7$ the dots are not independent observations, but indicate the probable extension of the distribution-curve. The smooth full-drawn curve is computed from the distributions of absolute magnitudes and peculiar velocities. The dotted curve shows the distribution when the supergiants are excluded.

y in Table III. The fourth and the last columns of Table II show the difference between observed and computed distributions. The computed distribution-curves are shown in Figures 1 and 2 as continuous curves, observed values being indicated by dots connected by straight lines.

Table III shows the distribution of $y_1 = \log |V'| - 1.6756$ and

of $y_2 = \log |V_0 + \epsilon / \sin \lambda| - 1.6756$. These distributions have been smoothed graphically and are reduced to a total of 1000 stars. The absolute magnitudes at which the transition from one distribution to the next occurs are given at the top between the columns.

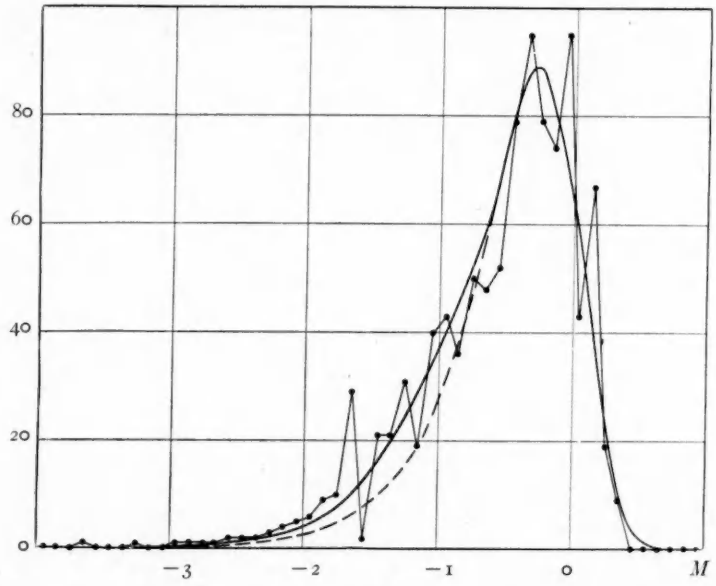

FIG. 2.—Distribution of $x_2 = \log v + 0.2m - \log \sin \lambda$ for stars of spectral type M. Similar to Fig. 1, but the computed curve is based on a combination of group motions and peculiar velocities.

At the bottom of Table III are given the mean values of y_1 and y_2 for the different absolute magnitude groups. These may be used for computing mean absolute magnitudes when the mean of the logarithms of the τ- or v-components is given. The following formulae then hold,

$$M = 5\ \overline{\log \tau} + \bar{m} - 5\ \bar{y}_1$$
$$M = 5\ \overline{\log v} + \bar{m} - 5\ \overline{\log \sin \lambda} - 5\ \bar{y}_2$$

The formulae for parallactic motions can be used only if the stars are well distributed over the sky, since this assumption is involved in the derivation of y_2.

TABLE III

y	$F(y_1)dy$				$F(y_2)dy$			
	−3.0	−1.2	−0.2		−3.0	−1.2	−0.2	
−3.6	1	1	1	1	0	0	0	0
−3.5	0	0	0	0	0	0	0	0
−3.4	0	0	0	0	0	0	0	0
−3.3	0	0	0	0	0	0	0	0
−3.2	0	1	0	0	0	1	1	1
−3.1	1	0	1	1	1	0	0	0
−3.0	0	0	0	0	0	0	0	0
−2.9	1	1	1	0	0	1	1	1
−2.8	1	1	1	1	1	0	0	0
−2.7	1	1	1	1	0	0	0	1
−2.6	1	1	1	1	1	1	1	1
−2.5	1	1	1	1	1	1	1	1
−2.4	2	2	2	2	1	1	1	1
−2.3	2	3	2	2	1	1	1	1
−2.2	3	3	3	2	2	2	2	2
−2.1	4	4	4	3	2	2	2	2
−2.0	5	5	5	4	2	2	3	3
−1.9	6	6	6	5	3	3	3	3
−1.8	7	8	7	6	4	4	4	4
−1.7	9	10	9	8	5	5	5	5
−1.6	12	12	11	10	6	6	7	7
−1.5	15	15	15	13	8	8	9	8
−1.4	19	19	18	15	9	10	11	10
−1.3	23	25	23	20	12	12	14	13
−1.2	29	31	29	25	15	16	17	17
−1.1	36	39	36	31	19	20	22	21
−1.0	44	48	45	38	24	25	27	26
−0.9	53	56	55	47	31	31	33	33
−0.8	63	67	65	57	39	41	40	40
−0.7	76	80	76	67	57	60	49	50
−0.6	93	92	93	82	76	71	62	59
−0.5	106	109	106	98	91	82	77	72
−0.4	111	112	111	109	103	102	93	86
−0.3	108	101	105	110	111	118	110	97
−0.2	86	79	83	100	117	121	117	107
−0.1	51	45	50	75	116	111	113	110
0.0	19	14	20	38	76	86	90	104
+0.1	7	5	10	21	44	38	54	70
+0.2	3	2	2	3	16	13	21	30
+0.3	1	1	1	2	5	4	6	10
+0.4	0	0	1	1	1	1	2	3
+0.5	0	0	0	0	0	0	1	1
+0.6								
$\bar{y}$	−0.618	−0.643	−0.617	−0.547	−0.402	−0.407	−0.396	−0.374

TABLE IV

M	$F(M)dM$	M	$F(M)dM$	M	$F(M)dM$
−5.6	1	−3.0	0	−0.4	79
−5.4	4	−2.8	0	−0.2	80
−5.2	8	−2.6	0	0.0	79
−5.0	11	−2.4	2	+0.2	73
−4.8	13	−2.2	8	+0.4	62
−4.6	14	−2.0	18	+0.6	40
−4.4	14	−1.8	32	+0.8	22
−4.2	13	−1.6	44	+1.0	14
−4.0	10	−1.4	53	+1.2	8
−3.8	4	−1.2	63	+1.4	4
−3.6	0	−1.0	72	+1.6	1
−3.4	0	−0.8	76	+1.8	
−3.2	0	−0.6	78		

For values of τ or v smaller than a certain limit δ (e.g., $\delta = 0''.01$), the observed values should be replaced by means based on a uniform or linear distribution around zero values. Russell[1] has proved that for a uniform distribution we can then replace each of the small values by δ/e, where e is the base of the natural logarithms. It is easily shown that the same formula holds for a linear distribution in the neighborhood of zero values, when all numbers are regarded as positive.

Table IV gives the final distribution of absolute magnitudes. This distribution was found by a simultaneous least-squares solution from equations of condition based on both τ- and v-components. The differences $M_2' - M_1'$, $M_3' - M_2'$ were taken equal to 0.4; that is, the interval in M was 2 mag. Four solutions with a shift of 0.1 in x and y were made simultaneously, with the result that the determination of $F(M)dM$ gave values for an interval of 0.5 mag. A curve drawn through the points representing the calculated frequencies is shown in Figure 3, and the final distribution with an interval of 0.2 mag. was derived from this curve.

The distribution of absolute magnitudes shown in Table IV and Figure 3 is of great interest. It shows a clear division into two groups: supergiants with a mean absolute magnitude of −4.5 and ordinary giants with a mean absolute magnitude of about zero. The

[1] *Publications of the Astronomical Society of the Pacific*, **32**, 243, 1920.

relative proportion of stars in the two groups is 9 and 91 per cent, respectively. The groups are separated by a clear gap extending from -2.5 to -3.5 mag.

A comparison of the new absolute-magnitude curve with that derived from the τ-components alone and published in *Contribution* No. 396[1] shows a marked difference. The earlier curve of absolute magnitude has two maxima, one at -1.6 and the other at -0.1 mag. The reason for this discrepancy is immediately seen from Fig-

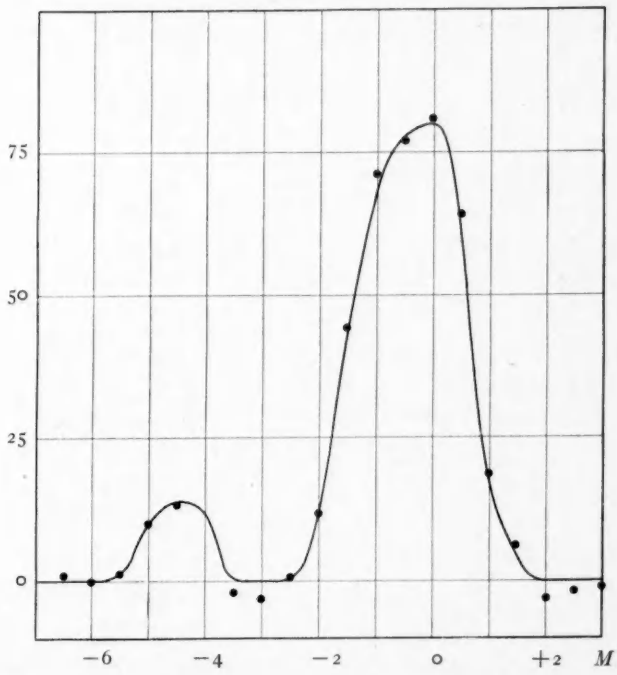

FIG. 3.—Distribution of absolute magnitudes for stars of spectral class M. The points are computed from the distribution of reduced τ- and v-components. Note the two frequency maxima.

ures 1 and 2 of the present paper. The observed distribution of reduced τ-components in Figure 1 shows a large drop at $x=-0.65$ to $x=-0.45$ and a subsequent rise to a new maximum at $x=-0.3$. These two maxima in $F(x)dx$ are responsible for the two maxima in

[1] *Astrophysical Journal*, **71**, 175, 1930.

$F(M)dM$. No such maxima appear in the distribution of the v-components, consequently they cannot be due to a minimum in the absolute-magnitude curve at -0.9 mag.

The reproduction of the distribution-curves of the τ- and v-components is, of course, not so good as that of the τ-components alone in the preceding study. The computed curve now lies above the observed distribution of τ-components for $x < -1.7$, and below the observed distribution of v-components in the same region. It is to be noted that the observed values of $F(x)dx$ for $x < -1.7$ are not independent of one another as are the values of $x > -1.7$.

In order to see more easily the effect of the supergiants on the distribution of τ- and v-components, I have indicated by a dotted smooth curve in Figures 1 and 2 the values of $F(x)dx$ after the supergiants have been subtracted.

The present results are in good agreement with the spectroscopic absolute magnitudes, except that the gap separating the supergiants from the giants does not show in the spectroscopic data. I have shown[1] that the accidental error in the spectroscopic absolute magnitudes for the supergiant M stars is much larger than for the ordinary giants, and the extra dispersion may well obliterate the gap in the luminosity-curve. The present value for the absolute magnitude of the supergiants is somewhat brighter than that given for the spectroscopically determined supergiants, but the difference is quite within the uncertainties of both determinations. It is quite possible that the true value of the average radial velocity θ for the supergiants is somewhat smaller than the adopted value of 17.4 km/sec. If so, the true mean absolute magnitude for these stars may be as much as half a magnitude fainter than the value -4.5 here given.

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July 1930

[1] *Mt. Wilson Contr.*, No. 327; *Astrophysical Journal*, **65**, 108, 1927.

SYSTEMATIC ERRORS IN THE DETERMINATION OF THE CONTOURS OF THE HYDROGEN LINES IN A STARS

By EMMA T. R. WILLIAMS

ABSTRACT

Evidence is adduced in support of the author's opinion that the systematic differences among the published contours of hydrogen lines are largely due to the judgment of the observer in estimating the position of the continuous background across the absorption line.

The exact measurement of absorption line contours in stellar spectra is complicated by a number of factors such as resolving power, suitable calibration, etc. One of the most troublesome things is the determination of the position of the continuous background. It is possible, of course, by assuming the distribution of energy to be that of a black body, and by assuming a suitable stellar temperature, etc., to derive for the particular instrument, air mass, etc., the theoretical continuous background by comparison with a terrestrial source of known temperature. But the delicacy required in the procedure is almost unattainable, and besides it is well known that the apparent distribution of energy of many stars is not that of a black body. Hence, the procedure which has been followed in most of the measurements of the contours of lines so far published has been to use personal judgment in drawing in the continuous background. For example, this probably gives rise to large systematic errors in the measures of the *H* and *K* lines of stars of late types, but the part played by personal judgment in drawing in the continuous background for $H\gamma$ and $H\delta$ in A stars has hitherto been considered to be relatively small.

However, large systematic differences are evident in a comparison of the contours recently published by C. T. Elvey[1] with those published by the writer.[2] It is only to be expected that the central depths of the lines, uncorrected for resolving power, as found by Elvey using a slit spectrograph with a dispersion of 8 A per millimeter at $H\gamma$ would be considerably deeper than those found by the writer

[1] *Astrophysical Journal*, **71**, 191, 1930. [2] *Harvard Circular*, **348**, 1929.

using an objective prism with a dispersion of 50 A per millimeter at $H\gamma$; but generally it has been assumed that the total energy absorption of the lines would be unaffected by the dispersion and the resolving power. It appears, however, that the matter of personal judgment as to where the continuous background should be drawn is, undoubtedly, the source of very large systematic differences in the total absorption of energy for A5 and Fo stars, whereas the two sets of measures are fairly accordant for B5, B8, and Ao stars.

TABLE I

1	2	3	4	5	6
B5–B8..	1.05± .03 *3*	0.93± .02 *5*	0.94± .03 *5*	.....	.....
Ao.....	1.10± .06 *4*	1.07± .04 *6*	1.09± .04 *6*	0.81± .04 *8*	0.86± .02 *7*
A2–A3..	1.02± .03 *5*	0.85± .04 *5*	0.85± .05 *5*	0.64± .07 *4*	.....
A5–Fo..	0.97± .02 *4*	0.68± .04 *6*	0.71± .04 *6*	.....	.....

Column 1 gives the Henry Draper class.

Column 2 gives the arithmetic mean, together with its probable error, of the ratios

$$\frac{\text{Central depth of } H\gamma \text{ measured by Elvey at Yerkes}}{\text{Central depth of } H\gamma \text{ measured by the writer}}$$

for all of the non-peculiar stars appearing on both lists. In italics, following, is given the number of stars contributing to the mean.

Columns 3–6 are similar in form to col. 2, but instead of comparing central depths of $H\gamma$ as in col. 2, col. 3 compares the width of $H\gamma$ at residual intensity equal to 0.90 as measured by Elvey at Yerkes with those measured by the writer for the same stars; col. 4 compares the total absorptions of $H\gamma$ measured by Elvey at Yerkes with those measured by the writer for the same stars; col. 5 compares the total absorptions of $H\gamma$ computed from measures by Elvey at Dearborn with those measured by the writer for the same stars; col. 6 compares the total absorptions of $H\gamma$ measured by Dunham at Harvard with those measured by the writer for the same stars.

In order to compare Elvey's measures with the writer's, it should be noted that at $H\gamma$ the unit of total absorption used by the writer is 0.188 times that used by Elvey, as is also the unit of line width. To compare the line depths, the writer's central depths have been converted into percentage of loss of light. The systematic differences mentioned above are shown in the fourth column of Table I. To obtain the first line of the fourth column, the ratio of the total absorption as found by Elvey to that found by the writer for each of the non-peculiar B5–B8 stars in common to the two lists was found. These were 0.94, 0.98, 0.96, 0.78, and 1.04; the arithmetical

mean of these is 0.94, with a probable error of ±0.03; which are the figures given in the table. The figures in the other columns are obtained in a similar manner. Only three stars, instead of five, contribute to the mean in the first line of column 2, since Elvey was unable to measure the total loss of light at the center of $H\gamma$ for two of the five stars included in the first line of column 4. Column 3 gives the mean of the ratios of the width of $H\gamma$ at a residual intensity (r) equal to 0.90. The values in column 3 are very similar to those in column 4, of course, since the width of the line at $r = 0.90$ usually gives a fair measure of the total absorption of the line.

An examination of the items in column 4 leads to the conclusion that probably there is no large systematic difference in the total absorption in B5, B8, and A0 stars, but that systematic differences begin to appear in A2 and A3 stars and are very considerable in A5 and F0 stars. This would seem to indicate that the writer draws the continuous background systematically higher than does Elvey in the case of a star whose continuous background is broken up by many fine lines. This is confirmed by the fact that the central depths measured by Elvey in A5 and F0 stars are no greater than those measured by the writer, who was using *much* smaller resolving power (see col. 2). In the case of the two F0 stars the background is drawn about 0.09 mag. higher by the writer than by Elvey.

That the difficulty is not so much a matter of dispersion as of personal judgment is shown by the fact that Elvey's measures of the total absorption of $H\beta$ and $H\gamma$ in the solar spectrum are, respectively, 63 and 59 per cent of the values obtained from Unsöld's contours of the same lines[1] made at Mount Wilson with about thirty times the dispersion used by Elvey.

Column 5 of the table compares the total absorption derived from measures which Elvey made at the Dearborn Observatory[2] with the total absorption found by the writer for the non-peculiar stars which appear on both lists. The comparison is made with the writer's measures rather than with Elvey's more recent measures because there are more stars available for the comparison. The Dearborn equipment had a slit spectrograph with a dispersion of 39 A per millimeter at Hγ, this being about one-fifth the dispersion used with

[1] *Zeitschrift für Physik*, **59**, 353, 1930. [2] *Astrophysical Journal*, **68**, 145, 1928.

the Yerkes spectrograph. By comparing corresponding items in columns 4 and 5 we see that Elvey measures total absorption rather smaller with lower dispersion than with high dispersion. Perhaps, however, the published parameters of the Dearborn measures[1] are not suitable for the computation of total absorptions as we have computed them.

Column 6 gives a comparison of T. Dunham's measures[2] of the total absorption of $H\gamma$ with the writer's. Dunham used the same instrumental equipment and method of calibration which were subsequently used by the writer. For the seven non-peculiar Ao stars common to the two lists, the mean ratio of the total absorptions of $H\gamma$ measured by Dunham is $0.86 \pm .02$ of the total absorptions for the same stars measured by the writer; for the depths of the lines[3] the ratio is 0.97 ± 0.01. If the writer had drawn the continuous background only .03 or .04 mag. lower, or if Dunham had drawn it .03 or .04 mag. higher, the two sets of the total absorptions would have been equal as would have been the central depths.

As a result of these systematic differences, Elvey finds that the maximum total absorption of $H\gamma$ occurs in Ao stars, whereas the writer finds it somewhere between A2 and A5. Moreover, the determination made by Miss Payne and the writer[4] of the spectral class in which $H\gamma$ and $H\delta$ attain maximum width at various residual intensities is possibly greatly affected. Thus, they found that for $r = 0.48$ the maximum width occurs at Ao, but for $r = 0.96$ it occurs at types A3–A5. As pointed out in that paper, if they have drawn the continuous background of the A3–A5 stars systematically 0.06 mag. higher than for the Ao stars, the maximum width for all residual intensities would be found at Ao.

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[1] Elvey published two parameters, I_o and k, to characterize each line, and gave the equation of the contour of the line as

$$I = I_o e^{-k(\lambda - \lambda_o)}.$$

From this the total absorption expressed in frequency units at $H\gamma$ is found to be

$$\frac{1}{2\lambda^2 \times 10^8} \int_{\lambda_0}^{\infty} I d\lambda = 10.6 \frac{I_o}{k}.$$

[2] *Harvard Bulletin*, **853**, 8, 1927. [3] *Ibid.*, **858**, 7, 1928.

[4] *Monthly Notices of the Royal Astronomical Society*, **89**, 526, 1929.

REVIEWS

Astronomy, an Introduction. By ROBERT H. BAKER. New York: D. Van Nostrand Co., 1930. Pp. xix+521. Figs. 336. $3.75.

This text will readily commend itself to teachers who give courses of a full year in colleges. The subject matter is well chosen, and skilfully presented. No knowledge of mathematics, beyond the minimum of algebra, geometry, and trigonometry, which American colleges require, is assumed on the part of the reader. Illustrative problems are given in connection with such subjects as conversion of time, angular and linear dimensions of the heavenly bodies, and stellar magnitudes, but there are no review questions at the ends of the chapters.

In the first chapter are shown forty-nine constellations of the equatorial and north-polar regions on small-scale maps. Accompanying these is a table of the Latin names of forty-four constellations, with the endings of the genitive forms, the English equivalents, declination, and the months in which they appear on the meridian in the early evening. No doubt this list contains all the groups a student is likely to learn in a first course. Yet it seems that space might have been found in the table for all the constellations recognized by astronomers. For somewhere in his textbook a student should be able to find the relative positions of such frequently mentioned objects as the Southern Cross, the Magellanic Clouds, Alpha Centauri, and Canopus.

At the ends of the different chapters are to be found judiciously selected references to classical treatises, recent monographs, and the current astronomical publications. These will indicate to teachers what their library shelves should contain on the subject of astronomy, as well as lighten the task of directing the supplementary reading of their students.

The author has searched the most recent publications for data on live questions, including even a summary of what is known about Pluto. The book is free from hobbies and pet theories. Matters in controversy and hypotheses only tentatively advanced are treated with caution and fairness. The reader is made to feel that there are still outstanding problems in astronomy.

A brief statement of the Einstein theory of relativity appears in chapter iv, together with the three tests for which astronomy offers the only data.

The author adds, "these have received considerable attention, and in each case the observational evidence appears to support the theory of relativity."

Under the heading "Origin of the Solar System" Laplace's Nebular Hypothesis is presented with such obvious sympathy that the reader suspects it was reluctantly pronounced untenable in the light of later knowledge. The theories of Chamberlain and Moulton, as also those of Jeans and of Jeffreys, are set forth but not as by an advocate.

Are there other planetary systems than that of which the earth is a member? The discussion of this question is concluded in these words: "If the encounter theory is correct, systems of planets are probably rare. But in the whole physical universe their number could still be very great, and the number of planets capable of supporting life might be very great also."

The structure of the atom and the quantum theory are discussed in connection with the study of light. In harmony with the growth of knowledge, relatively more space is given to the stars than in the books of a generation ago. Magnitude, parallax, proper motion, and radial velocity receive satisfactory treatment.

The rapid increase in the number of known double stars, the significance of stellar variation, and even the attacks on the problem of the internal constitution of the stars—all call for more space. However, the book is not too extensive, and the general reader, no less than the college student, will find it fresh and interesting.

The numerous diagrams are well drawn, and the reproductions from photographs are uniformly good. The paper and the binding are of high quality.

W. F. Long